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Narragansett Bay Sustainability Pilot

Model Description | September 13, 2013

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ORD contact: Marilyn ten Brink

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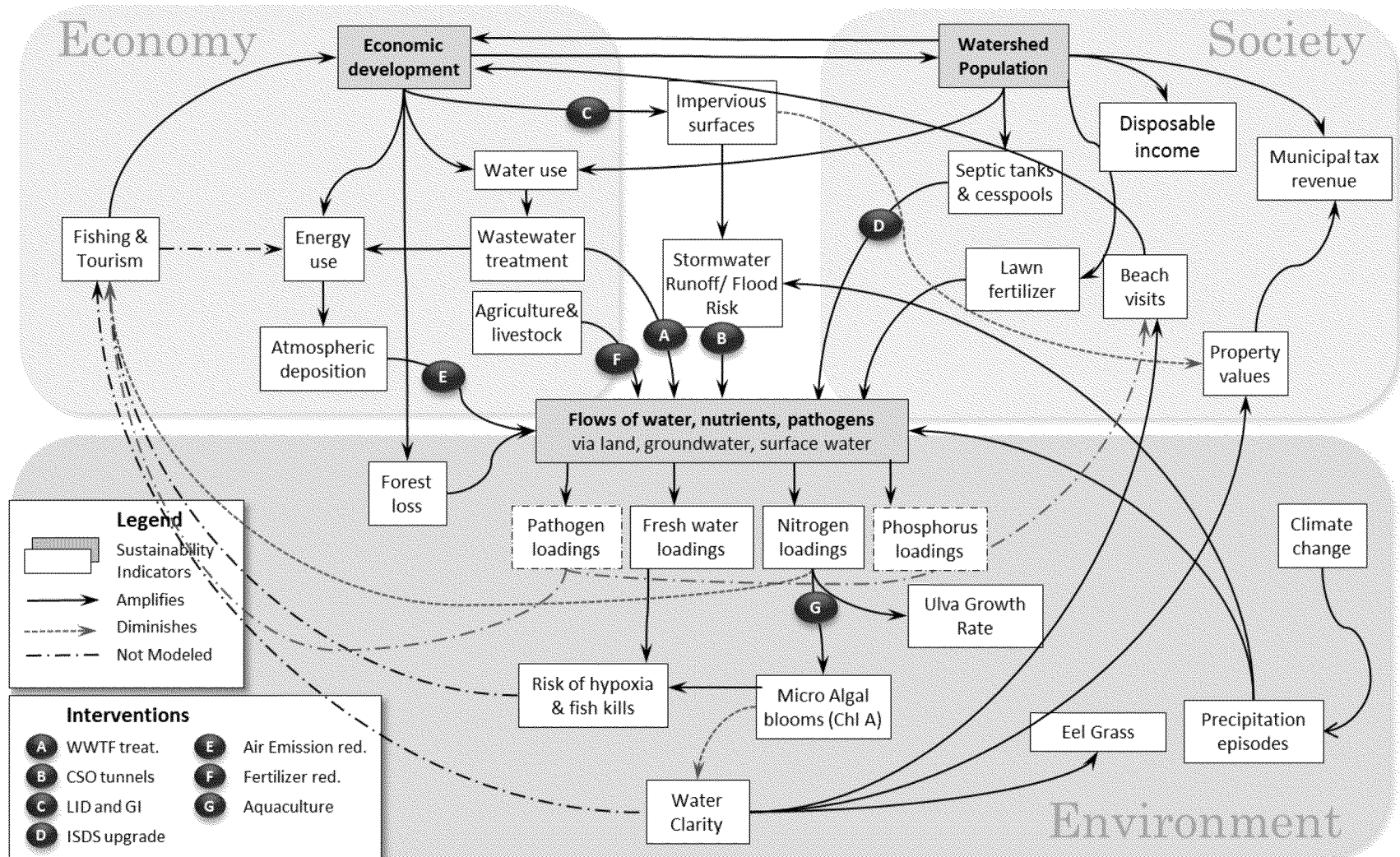
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SECTION 1 | INTRODUCTION

This document provides an overview of the data sources and relationships used to develop the Narragansett 3VS model. It is meant to provide the reader with a thorough understanding of what is included in the model and how the model was developed. For a complete documentation of the model, refer to a separate document, "Narragansett Model Documentation."

This section presents a schematic that uses the triple-value framework to of economy, society, and environment to illustrate the primary variables included in the Narragansett 3VS model, as well as key relationships among them. Exhibit 1-1 illustrates both variables and relationships included in the model (solid lines) as well as those that are not included in the model (dashed lines), though they are important elements of the system that the model represents. Black lines indicate amplifying causal relationships while red lines indicate diminishing causal relationships. Interventions are represented by green circles and situated on the targeted causal relationship.

The main elements of the schematic can be grouped into loadings (boxes with arrows pointing toward the grey box labeled "Flows of water, nutrients, pathogens via land, groundwater, surface water"), environmental relationships (boxes in the "Environment" section of the schematic), and impacts on economy and society (all other boxes). A summary of all indicators included in the model can be found in Section 2. Additional information about how the model estimates nitrogen loadings can be found in Section 3. Section 4 discusses how the model simulates the flow of nitrogen within Narragansett Bay, which is the primary driver of environmental impacts of nitrogen pollution. Section 5 discusses the various policy interventions included in the model, and Section 6 provides detailed information about the environmental, economic, and social impacts of nitrogen loadings to Narragansett Bay. The final section of this document, Section 7, summarizes additional research conducted during the development of the Narragansett 3VS model, including additional information related to the data sources that we used to develop the model, other models that indirectly guided the development of the model, data sources that could contribute to future versions of the model, and data sources that were determined not to fit the scale and scope of this model.

Legend

Sustainability Indicators

→ Amplifies

Diminishes

— · · — Not Modeled

Interventions

A — WWTF treat.
B — CSO tunnels
C — LID and GI
D — ISDS upgrade
E — Air Emission red.
F — Fertilizer red.
G — Aquaculture

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SECTION 2 | SOCIAL, ECONOMIC, AND ENVIRONMENTAL INDICATORS

In this section, we list the key economic, social, and environmental indicators included in the Narragansett 3VS model. These indicators – including both quantitative and semi-qualitative indicators – are the outputs that the model generates to illustrate the impacts of different policy scenarios (including the baseline, "no further action" scenario) on the human and physical environment of the Narragansett Bay system. Exhibit 2-1 lists the indicators in the model, together with the unit for each indicator. Exhibit 2-2 lists indicators that were considered for inclusion, but ultimately not included in the model. We include this list to demonstrate the breadth of the interactions among the project team and stakeholders in exploring the potential scope of indicators to include in the model. The exhibit provides a brief summary of why each indicator was not included in the current version of the model; additional information on our research into these variables can be found in Section 7. As noted in that section, there are instances where indicators may be added to future iterations of the model as more information and resources become available, or as the model is applied to additional locations.

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EXHIBIT 2-1. INDICATORS INCLUDED IN THE MODEL QUANTITATIVELY

CATEGORY	INDICATOR	UNIT
Economic/Social	GDP (change relative to baseline)	US$
Economic/Social	Per Capita Disposable Income	US$
Economic/Social	Property Value: - Related to Water Clarity - Related to Proximity to Open Space (LID/GI Use Case only)	US$
Economic/Social	Municipal Tax Revenue (related to changes in property value)	US$
Economic/Social	Employment (related to aquaculture)	Jobs
Economic/Social	Commercial Fish Production (finfish landings: total value and change relative to baseline)	US$
Economic/Social	Energy Use (energy demand curve for different levels of nitrogen removal)	Billion BTU
Economic/Social	Beach Visits	People
Economic/Social	Tourism Production (consumer surplus from beach visits: change relative to baseline)	US$
Economic/Social	Total Direct Cost of Nitrogen Reductions: Includes costs of - Aquaculture (calculated as US$/farm), - ISDS Improvements (US$/unit upgraded) - WWTF Reductions (US$ for O&M and annualized capital cost/kg N reduced) - Subwatershed-scale LID/GI Implementation (US$/kg N reduced) - LID/GI Use Case Retrofits (US$/acre of impervious cover reduced below initial levels) - Residential and Agricultural Fertilizer reductions (US$/kg N reduced), and - Animal Waste Reductions (US$/kg N reduced).	US$
Economic/Social	Aquaculture Revenue	US$
Environmental	Total Nitrogen Loadings, by Box (area of the Bay), subwatershed loading area, and source type: - WWTFs - ISDSs - Residential and Agricultural Fertilizer - Animal Waste - Atmospheric Deposition (direct to the Bay and via the watershed) - Surface Water Runoff from Developed Land	kg
Environmental	Nitrogen Concentration (by Box)	mg/L
Environmental	Micro Algal Blooms (chlorophyll A)	µg /L
Environmental	Ulva Growth Rate	Percent
Environmental	Hypoxia Risk (semi-qualitative)	Unitless
Environmental	Water Clarity/Secchi Depth	NTU
Environmental	Eel Grass Improvement Potential (semi-qualitative)	Unitless
Environmental	Precipitation (can be adjusted to reflect expected impacts of climate change on precipitation event frequency and size)	ml

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EXHIBIT 3-2. INDICATORS NOT MODELED

CATEGORY	INDICATOR	COMMENT
Economic/Social	Human Health	After interviewing contacts at the Rhode Island Department of Health and other experts, we found that pathogens (stored in seaweed and macroalgae) are the primary source of beach-related illness. Because pathogen loadings are not currently modeled, we do not model health impacts. Additional health impacts are tied to air emissions (especially particulates). The current version of the Narragansett 3VS model includes reductions in N deposition from air emissions, but does not address the associated reductions in particulate concentrations.
Economic/Social	Aesthetics	We were not able to establish a relationship between nitrogen loadings and aesthetics; however, we do estimate the effects of nitrogen loading on water clarity, which in turn affects property value and beach visits.
Economic/Social	Access to Water	We were not able to establish a relationship between nitrogen loadings and access to water; however, we do model other indicators that relate to water access, such as beach visits.
Economic/Social	Human Well-Being	Stakeholders raised this as a potential indicator to include in the model. The project team determined that indicators of overall human well-being indicators were beyond the scope for the current model; however they could be addressed in future versions of the model or in applications of the model to other locations
Economic/Social	Social Justice	Stakeholders raised this as a potential indicator to include in the model. The project team determined that social justice indicators were beyond the scope for the current model; however they could be addressed in future versions of the model or in applications of the model to other locations.
Economic/Social	Flood Risk	EPA has researched the effects of LID/GI on reducing flood risk. We explored the potential of incorporating regression data on the relationship of open space and flooding, but additional effort is required to tie flood risk directly to imperviousness, which is the key parameter driven by the use of LID/GI.
Economic/Social	Recreational Fishing and Boating	We were not able to establish a relationship between nitrogen loadings and recreation and therefore do not model impacts on recreational fishing and boating. However, we do model the impact of nitrogen on commercial fish landings.
Economic/Social	Tourism (beyond beach visits)	We were not able to establish an overall relationship between nitrogen loadings and tourism. Additionally, the quantitative, Bay-specific data on tourism that we identified are out of date so further research would be necessary to update these data.
Economic/Social	Shellfish Growth Rate	In developing the 3VS model, we explored including a relationship between nitrogen loadings and shellfish

		growth rate. However, the available data on this relationship did not appear to capture the full range of effects of nitrogen loading on growth rate. We therefore decided to exclude shellfish growth rates from the model, rather than presenting an incomplete picture of the impact of nitrogen on shellfish.
Economic/Social	Employment Impacts (beyond aquaculture)	A study by Stratus Consulting ("A Triple Bottom Line Assessment of Traditional and Green Infrastructure Options for Controlling CSO Events in Philadelphia's Watersheds") estimated the employment benefits of implementing LID/GI in Philadelphia, but the study did not provide sufficient information to allow us to apply their approach to the Narragansett Bay watershed. Further investigation of this indicator may be warranted for future versions of this model and applications of it to other locations.
Environmental	Greenhouse Gas Emissions	For this version of the model, we focused on indicators that would have a more immediate local impact, in order to better demonstrate the potential for feedback loops within the system.
Environmental	Metals Loading	We found data on the impact of specific LID/GI Best Management Practices (BMPs) on reducing metals loading, but no data on baseline metals loading or on environmental relationships between metals and other indicators.
Environmental	Phosphorus Loading	The SPARROW model provides estimates of phosphorus loadings from rivers, but we did not identify data sources for other sources of phosphorus loadings. In addition, because the primary focus of the Narragansett 3VS model is on the impact of nitrogen pollution in coastal waters, we did not research the environmental impacts of phosphorus pollution, which are primarily focused in freshwater environments.
Environmental	Pathogen Loading	We recognize that pathogens affect human health by contributing to beach closures and advisories, but we were not able to find data for pathogen loadings or for relationships between pathogens and other variables.
Environmental	Sediment Loading	We found data on the impact of specific LID/GI BMPs on reducing sediment loading, but no data on baseline sediment loading or on environmental relationships between sediment and other indicators.
Environmental	Groundwater recharge	Stakeholders raised this as a potential indicator to include in the model. The project team determined that groundwater recharge was beyond the scope for the current model; however they could be addressed in future versions of the model or in applications of the model to other locations
Environmental	Dissolved Oxygen	A quantitative dissolved oxygen metric is beyond the scope of the bio-physical realism of the 3VS model. The primary interest in dissolved oxygen is as a measure of hypoxia. The model incorporates a qualitative summer hypoxia metric based on changes in the hypoxia risk factors of precipitation, bay location, and nitrogen concentration.

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SECTION 3 | NITROGEN LOADINGS

To represent the problem of nitrogen pollution in Narragansett Bay, we designed the nitrogen loadings module in the Narragansett 3VS model to accomplish the following goals:

1. Estimate nitrogen loadings dynamically, using other variables estimated endogenously within the model.

2. Where possible, calibrate estimated nitrogen loadings to match observed data on nitrogen loadings in Narragansett Bay.

3. Disaggregate loadings by source category, by region (or "box") of the bay, and by season.

In accomplishing these goals, we relied primarily on two previously developed models of nitrogen loadings to Narragansett Bay and supplemented those models with site-specific and updated data sources, wherever possible. Exhibit 3-1 summarizes total nitrogen loadings by source category for the 14 bay boxes. The following sections present our approach for estimating nitrogen loadings in Narragansett Bay in the Narragansett 3VS model. We first describe the two previously developed nitrogen loadings models, then provide additional detail on each source category, and finally summarize the disaggregation of total loadings by bay box and by season.

MODELS OF NITROGEN LOADINGS

We used two models to develop the nitrogen loadings module within the Narragansett 3VS model:

4. A model of historical nitrogen loadings to Narragansett Bay, developed by Vadeboncoeur, Hamburg, and Prior (hereafter "VHP model") (2010).

5. The New England version of the SPARROW (SPAtially Referenced Regressions On Watershed attributes) model, developed by USGS (hereafter "SPARROW") (Moore et al. 2004).

This section summarizes how we used these two models to link nitrogen loadings to other variables in the model, calibrate nitrogen loadings to match observed data, and distribute loadings among the 14 boxes of Narragansett Bay.

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EXHIBIT 3-1. SUMMARY OF NITROGEN LOADINGS TO NARRAGANSETT BAY BY BAY BOX, 2002 (KG/YEAR)

Bay Box	Wastewater			Surface Water Runoff						Atm Dep Direct to the Bay	Total
	WWTF		ISDS	Undeveloped Land			Developed Land				
	Upshed WWTF	Bayside WWTF		Atm Deposition	Agricultural Fertilizer	Animals	Atm Deposition	Residential Fertilizer	Other Stormwater		
1	1,032,129	1,318,802	340,829	127,405	69,410	18,594	67,559	97,525	64,756	6,920	3,143,931
2	316,981	0	135,836	52,493	16,362	5,096	22,682	40,427	26,843	9,191	625,912
3	0	0	372	492	323	90	3,247	7,905	5,249	20,696	38,373
4	0	0	143	0	0	0	0	2,596	1,724	13,524	17,987
5	33,580	0	12,185	12,817	20,683	3,975	5,988	21,944	14,571	18,177	143,919
6	0	13,477	5,920	881	491	76	3,106	7,370	4,894	5,965	42,180
7	0	0	5,920	146	23	5	516	9,692	6,435	8,638	31,376
8	0	0	44,740	4,221	1,791	244	3,020	17,290	11,481	31,262	114,049
9	0	96,220	1,303	325	221	53	498	7,073	4,696	31,929	142,319
10	695,652	442,810	178,647	97,776	122,974	17,247	46,710	100,662	66,839	47,082	1,816,400
11	0	11,566	21,340	2,368	2,486	223	1,849	5,590	3,712	37,766	86,902
12	0	0	2,237	849	2,645	619	1,220	4,963	3,296	28,781	44,610
13	0	0	24,326	475	357	88	329	14,923	9,909	12,771	63,179
14	0	183,508	1,077	91	0	0	176	2,871	1,907	17,354	206,984
Total	2,078,342	2,066,384	774,877	300,339	237,766	46,310	156,901	340,833	226,311	290,057	6,518,120

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VADEBONCOEUR, HAMBURG, AND PRYOR (VHP) MODEL

The VHP model was developed for a study published in 2010 that estimated historic trends in nitrogen loadings to Narragansett Bay. This model uses literature-derived loading coefficients to estimate nitrogen loadings by source category from a set of independent variables, including sewered and non-sewered populations, atmospheric deposition, land cover (i.e., forested, agricultural, or developed), and fertilizer usage. The 2010 study found that historic nitrogen loadings estimated by the VHP model corresponded closely to observed values, both for the Narragansett Bay watershed as a whole and for the Pawtuxet, Blackstone, and Taunton subwatersheds.

For several source categories, we used the loading coefficients from the VHP model to relate nitrogen loadings by source category to other variables calculated endogenously within the model. This method allowed us to estimate nitrogen loadings dynamically in the model. That is, as key variables in the model (e.g., population, land use, air emissions) change over time or in response to policy interventions, nitrogen loadings to Narragansett Bay change accordingly. Exhibit 3-2 lists the source categories used in the VHP model, together with the variables used to derive loadings from each source, as well as the model's estimated nitrogen loadings for 2000.

EXHIBIT 3-2. SOURCE CATEGORIES AND INDEPENDENT VARIABLES USED TO CALCULATE NITROGEN LOADINGS IN THE VADEBONCOEUR, HAMBURG, AND PRYOR MODEL

SOURCE CATEGORY	INDEPENDENT VARIABLE(S)	ESTIMATED LOADINGS IN 2000 (KG)
Wastewater from Treatment Facilities	Sewered population	4,043,000
Wastewater from Independent Sewage Disposal Systems (ISDS)	Non-sewered population	1,089,000
Runoff from Animal Waste	Animal stock	195,000
Runoff from Agricultural and Suburban Fertilizer	Fertilizer application per hectare	1,020,000
Runoff from Atmospheric Deposition on the Watershed	Total N deposition per hectare; land use distribution (forest/agricultural/developed)	1,349,000
Atmospheric Deposition Direct to the Bay	Total N deposition per hectare	276,000
Total		7,972,000

For 2000, the VHP model estimates that total nitrogen loadings to Narragansett Bay from these six source categories were 8.0 million kg (as a best estimate, with a range between 4.3 million and 12.7 million kg).

NEW ENGLAND SPARROW MODEL

SPARROW is a regression-based model that estimates nitrogen loadings by source category, calibrated so that total estimated nitrogen loadings match observed nitrogen fluxes through river networks. Because SPARROW estimates nitrogen loadings for each river flowing into the bay, it provides us with a means of estimating total loadings separately by bay box. SPARROW disaggregates total nitrogen loadings among five source categories, as summarized in Exhibit 3-3.

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EXHIBIT 3-3. CATEGORIES OF NITROGEN LOADINGS SOURCES IN THE NEW ENGLAND SPARROW
MODEL AND ESTIMATES OF 2002 LOADINGS TO NARRAGANSETT BAY

SOURCE CATEGORY	SPARROW CATEGORY	ESTIMATED LOADINGS IN 2002 (KG)
Wastewater from Treatment Facilities	Sewered Population	1,932,513
Runoff from Animal Waste	Manure	48,795
Runoff from Agricultural Fertilizer	Corn, Soy, and Alfalfa Fertilizer + Other Fertilizer	248,982
Runoff from Atmospheric Deposition on the Watershed (excluding developed land)	Atmospheric Deposition via Watershed	465,590
Runoff from Developed Land	Developed Land	1,355,519
Total		4,051,399

SPARROW estimates that total nitrogen loadings from these five source categories were 4.1 million kg in 2002. Notably, the SPARROW loading source categories differ from the VHP categories – SPARROW includes surface water runoff from developed lands but does not include unsewered population or atmospheric deposition direct to the bay. In addition, because SPARROW is calibrated to equal total nitrogen flux from rivers, it does not capture nitrogen loadings from sources that discharge directly to the bay, including several of the largest wastewater treatment facilities (WWTFs) in the watershed. Finally, SPARROW provides data on nitrogen loadings to Narragansett Bay for only 2002, making it useful for calibration purposes, but limiting its ability to help model nitrogen loadings dynamically.[1]

The following sections discuss in greater detail how we used the VHP and SPARROW models, together with other data sources, to dynamically model nitrogen loadings to Narragansett Bay.

NITROGEN LOADINGS BY SOURCE CATEGORY

This section discusses how the nitrogen loadings module estimates loadings dynamically for nine different source categories, which can be grouped into the following three broad categories:

1. Nitrogen from wastewater, including from (1) wastewater treatment facilities (WWTFs) and from (2) independent sewage disposal systems (ISDSs);

2. Nitrogen from surface water runoff, including from (3) animal waste, from (4) agricultural and (5) residential fertilizer, from atmospheric deposition on the watershed – both on (6) undeveloped and (7) developed land – and from (8) other sources of urban runoff; and

3. Nitrogen from (9) atmospheric deposition direct to the bay.

Exhibit 3-4 summarizes the source categories used in the model. As the exhibit shows, the primary variables in the model affecting nitrogen loadings are precipitation, population, impervious cover, and air emissions of nitrogen.

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[1] Additional information on the SPARROW model is available at http://water.usgs.gov/nawqa/sparrow.

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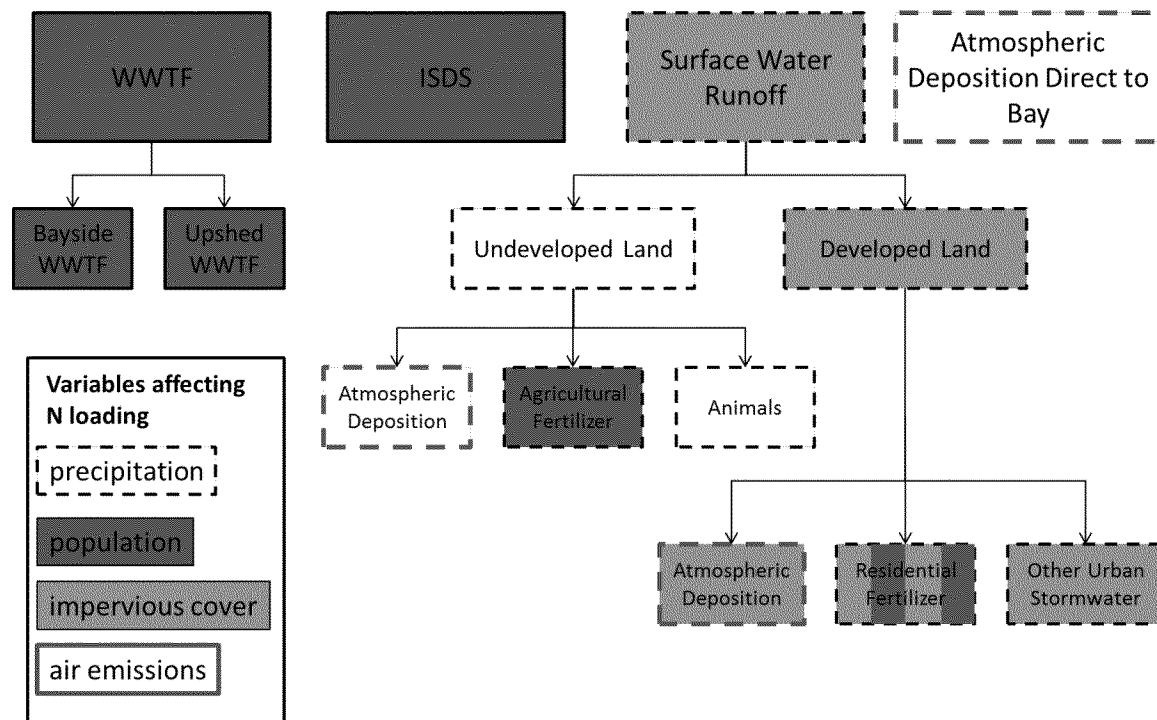
WASTEWATER TREATMENT FACILITIES (WWTFS)

For nitrogen loadings from WWTFs, we obtained facility-specific enforcement and compliance monitoring data for both MA and RI for the years 2000-2010. These datasets, which include average monthly effluent nitrogen concentrations and flow for all facilities in the Narragansett Bay watershed, allowed us to calculate more recent estimates of nitrogen loadings from wastewater from the sewered population than were available in either the VHP model or SPARROW. In addition, we used the monthly effluent data to disaggregate annual WWTF loadings by season, thereby capturing the effects of regulations limiting summer nitrogen concentrations.[2] The model groups WWTF loadings into "bayside" (i.e., those that discharge directly into Narragansett Bay) and "upshed" (i.e., those that discharge into rivers that flow into the bay), in order to facilitate comparison to SPARROW's estimate of loadings for this category. SPARROW's estimate of WWTF loadings in 2002, which includes only upshed facilities, is 1.9 million kg; based on the enforcement and compliance monitoring data, the Narragansett 3VS model estimates 2002 loadings of 2.1 million kg for the same facilities.

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[2] Note that for selected Rhode Island facilities there are additional agreed-upon reductions to be implemented by 2014. To obtain the loadings for these facilities in 2014, we relied on presentation given by the Rhode Island Department of Environmental Management that reported effluent concentrations at these facilities in 2008-2009 as well as 2014 target concentrations for each facility. For each facility, we calculated 2014 loadings by multiplying loadings in 2008-2009 by the ratio of 2014 target effluent concentrations to reported 2008-2009 effluent concentrations.

In order to estimate WWTF loadings dynamically in the model, we divided summer and winter loadings for each facility by the estimated population that the facility served, yielding facility-specific seasonal per-capita loading coefficients. These coefficients allow the model to project changes in nitrogen loadings based on population changes, assuming that treatment levels remain constant.

Data sources used for this source category include:

- Monthly WWTF loadings in MA, 2000-2010: EPA's compliance and enforcement monitoring data.

- Monthly WWTF loadings in RI, 2000-2010: RIDEM compliance and enforcement monitoring data.

- Effluent concentrations at selected RI facilities, both current and target limits: Liberti, A. 2010. CHRP/Managers Meeting Presentation. Rhode Island Department of Environmental Management. December 9.

- Population served, RI facilities: WWTF RIDEM Office of Water Resources listing of Wastewater Facilities and Contacts. Available at http://www.dem.ri.gov/programs/benviron/water/permits/wtf/potwops.htm.

- Population served, RI facilities: EPA Clean Watersheds Needs Survey 2008 Data and Reports: Detailed listing of Wastewater Treatment Plants Flows and Population Receiving Treatments for State of Massachusetts. Available at http://iaspub.epa.gov/apex/cwns2008/f?p=115:1:0::NO::: (query Wastewater Treatment Plant Flows and Population Receiving Treatment for the state of Massachusetts).

INDEPENDENT SEWAGE DISPOSAL SYSTEMS (ISDS)

As noted above, the VHP model estimates nitrogen loadings for wastewater from the non-sewered population, but SPARROW does not.[3] From discussion with state stakeholders and EPA, we determined that the VHP model likely overestimates loadings from independent sewage disposal systems (ISDSs). Accordingly, we used the following process to estimate ISDS loadings, disaggregated by bay box:

1. We first used GIS software to map the sewer system infrastructure in the Narragansett Bay watershed. For Rhode Island, we obtained the most up-to-date infrastructure data available from RIDEM. For Massachusetts, we obtained infrastructure data from the City of Fall River and the City of Taunton; we were not able to obtain GIS data from the City of Somerset.

2. We then determined the number of people in the watershed using ISDSs that discharge into Narragansett Bay. We first mapped known buildings or structures in Rhode Island using 2012 E-911 data obtained from RIGIS. Next, we determined the number of these structures that a) fall outside of the areas with sewer system infrastructure, and b) are located on soils with high infiltration rates that are connected to the Bay or that overlap rivers and streams leading to the Bay. Using 2010 census data on the average population per structure in Rhode Island, we estimated the number of people in Rhode Island using ISDSs that discharge into the bay.

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[3] Because SPARROW is calibrated so that total estimated nitrogen loadings by source category equal total observed nitrogen flux in rivers, it is likely that it does capture nitrogen loadings from ISDSs, but it attributes them to a different source category (such as "Developed Land"). As will be seen later, our estimate of total loadings to Narragansett Bay (excluding bayside WWTFs and atmospheric deposition direct to the bay), is approximately equal to SPARROW's estimate, though we distribute total loadings among source categories differently.

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Dividing that number by the population of Rhode Island yielded an estimate of the percent of the population using ISDSs that discharge to the bay.[4] We then multiplied this number by the population of the watershed to produce an estimate of the total non-sewered population with nitrogen loadings that reach the bay.

3. To estimate the amount of nitrogen that these systems contribute to the bay, we first use a baseline per-person nitrogen value of 4.4 kg/person/year from the VHP model. We then assume that typical systems remove 10% of nitrogen (via attenuation and other processes), and that upgraded systems remove 20% of nitrogen.

Data sources used for this source category include:

- Per capita wastewater N loading coefficients: VHP Model.

- Sewer system infrastructure, RI: T. Peters, RIDEM, personal communication, March 21, 2012.

- Sewer system infrastructure, MA: J. Garcia, City of Fall River, personal communication on April 18, 2012; A.M. Teves, City of Taunton, personal communication on April 23, 2012.

- Locations of buildings or structures, RI: RIGIS, 2012.

- Soils information: N. Detenbeck, personal communication, August 16, 2012.

- Average population per building: U.S. Census, 2010.

- N removal efficiency for baseline and upgraded ISDS: A. Gold, personal communication on May 15, 2012; National Environmental Services Center, 2012; and J. Boyd, personal communication, June 21, 2012.

ANIMAL WASTE (AGRICULTURAL LIVESTOCK)

The VHP model uses historical county-level data on livestock populations, together with nitrogen transport coefficients to estimate total nitrogen loadings from livestock, which it calculates as just under 200,000 kg in 2000. We assume that livestock populations remain constant throughout the timeframe of the model. The SPARROW model estimates lower nitrogen loadings from manure than the VHP model (46,000 kg). For this loadings category, we assume that SPARROW has the more accurate estimate (because it accounts for any attenuation of nitrogen from livestock within the watershed), so we adjusted the nitrogen transport coefficients from the VHP model so that total loadings from animal waste equal the total estimated by SPARROW. Because loadings from animal waste reach the bay via surface water runoff, precipitation influences total loadings from this source category in the Narragansett 3VS model.

Data sources used for this source category include:

- Historical livestock populations for the watershed: VHP Model.

- Total loadings from animal waste, disaggregated by bay box: SPARROW.

- Precipitation: National Weather Service Forecast Office. Monthly Weather Summary. Providence (TF Green Airport).

AGRICULTURAL FERTILIZER

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[4] E-911 data were not available for Massachusetts, so we assume that the percentage of the population using ISDSs that discharge into the Narragansett Bay is constant across the watershed.

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The VHP model uses county-level fertilizer application data to estimate total nitrogen loadings from fertilizer, assuming that 25 percent of total fertilizer applied in the watershed reaches the bay. For 2000, the VHP model estimates that total loadings from fertilizer, including both agricultural and suburban (e.g., lawns, gardens, and golf courses) were over one million kg. The SPARROW model estimates loadings from two categories of agricultural fertilizer: "corn, soy, and alfalfa fertilizer" and "other fertilizers." Rather than estimating loadings separately from suburban fertilizer, it includes this source as part of the "developed land" source category. Because agricultural and suburban fertilizer are driven by different factors, we decided to estimate them separately in the Narragansett 3VS model. For agricultural fertilizer, we divided SPARROW's loadings estimates by the amount of agricultural land in the watershed, yielding fertilizer application rates per hectare. To model loadings from agricultural fertilizer dynamically, we linked these rates to the population of the watershed; as the population increases, the rate of fertilizer application per hectare also increases, reflecting more intensive use of agricultural land. Furthermore, we found that linking fertilizer application rates to population produced an increasing trend of fertilizer use intensity that closely resembled the trend seen in the county-level data used in the VHP model. As with loadings from animal waste, loadings from agricultural fertilizer are also affected by precipitation.

Data sources used for this source category include:

- Historic fertilizer application rates: VHP Model.

- Disaggregated agricultural fertilizer loadings: SPARROW.

- Watershed population: NOAA's Spatial Trends in Coastal Socioeconomics (STICS) projections.

- Precipitation: National Weather Service Forecast Office. Monthly Weather Summary. Providence (TF Green Airport).

RESIDENTIAL FERTILIZER

To estimate loadings from residential fertilizer use (i.e., on lawns and golf courses), we first obtained data on the nitrogen content of Rhode Island residential fertilizer sales from Scott's Miracle-Gro Company, which serves approximately 50 percent of the residential fertilizer market in Rhode Island. Doubling the sales data yielded total residential fertilizer sales in Rhode Island. Dividing that number by the population of Rhode Island provided us with an estimate of per-capita nitrogen application rates for residential fertilizer, which we used to dynamically estimate nitrogen loadings from this source category. We then applied the nitrogen transport factor from the VHP model, meaning that 25 percent of nitrogen applied in residential fertilizer in the watershed eventually reaches the bay. As with other surface water runoff categories, loadings from residential fertilizer are influenced by precipitation as well.

Data sources used for this source category include:

- Fertilizer nitrogen transport coefficients: VHP Model.

- Total residential fertilizer sales in Rhode Island: Gina Zirkle, Scott's Miracle-Gro Company.

- Precipitation: National Weather Service Forecast Office. Monthly Weather Summary. Providence (TF Green Airport).

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ATMOSPHERIC DEPOSITION DIRECT TO THE BAY AND VIA THE WATERSHED

The VHP model estimates nitrogen loadings from atmospheric deposition direct to the bay, as well as from nitrogen that is deposited onto the watershed. For both categories, the VHP model uses a value of 10 kg/ha for 2000. For atmospheric deposition via the watershed, the VHP model uses different nitrogen transport coefficients for three categories of land use: forest (10%), agricultural land (20%), and urban land (65%). In 2000, the VHP model estimates about 280,000 kg in deposition direct to the bay and 1.3 million kg in deposition via the watershed. For the Narragansett 3VS model, we used the same framework to estimate nitrogen loadings from atmospheric deposition, combining deposition rates per hectare with land use-specific transport coefficients. However, we used updated data sources and the SPARROW model to improve the estimates provided by the VHP model.

We used EPA's Community Multi-scale Air Quality (CMAQ) model to obtain more precise and updated data on atmospheric deposition of nitrogen, including historical data for 2002 and projected data for 2020. The CMAQ output allowed us to estimate separate deposition rates for each bay box, ranging from 6.16 kg/ha in Box 13 to 12.35 kg/ha in Box 1. Using data from EPA's Section 812 Prospective Analysis of the benefits and costs of the 1990 Clean Air Act Amendments, we developed a trajectory of nitrogen deposition direct to the bay from 2002 (290,000 kg) to 2020 (200,000 kg), reflecting expected reductions in nitrogen emissions from Clean Air Act regulations on power plants and automobiles.

For atmospheric deposition via the watershed, SPARROW estimates total loadings of 460,000 kg in 2002, which is substantially lower than the value estimated by the VHP model. Rather than trying to reconcile these two estimates, which likely involve different definitions of what constitutes atmospheric deposition, we instead estimated three different categories of loadings related to atmospheric deposition:

1. Atmospheric deposition via the watershed, developed land: estimated by multiplying SPARROW's estimate of atmospheric deposition via the watershed by the percent of land area in the watershed that is developed;

2. Atmospheric deposition via the watershed, undeveloped land: estimated by multiplying SPARROW's estimate of atmospheric deposition via the watershed by the percent of land area in the watershed that is not developed; and

3. Other urban stormwater: estimated by calculating total nitrogen loadings from surface water runoff (using a method described in the following section) and subtracting other categories of surface water runoff (i.e., animal waste, agricultural and residential fertilizer, and atmospheric deposition via the watershed on both developed and undeveloped land).

We assume that this third category, "other urban stormwater" includes a portion of the loadings defined as atmospheric deposition via the watershed in the VHP model and a portion of the loadings defined as "developed land" in SPARROW. For 2002, we estimate that loadings from atmospheric deposition via the watershed were 300,339 kg on undeveloped land and 159,901 kg on developed land. As with other surface water runoff source categories, nitrogen loadings from atmospheric deposition via the watershed are affected by precipitation in the model.

Data sources used for this source category include:

- Historic atmospheric deposition data for 2002 and projected atmospheric deposition data for 2020, disaggregated by bay box: EPA's Community Multi-scale Air Quality model (CMAQ); Dr. Robin

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Dennis, EPA Atmospheric Modeling and Analysis Division.

- Trajectory of nitrogen emissions from 2002 to 2020: EPA's Second Section 812 Prospective Analysis of the Benefits and Costs of the 1990 Clean Air Act Amendments. Available at: http://www.epa.gov/air/sect812/prospective2.html.

- Land use distribution in the watershed and land use category-specific nitrogen transport coefficients: VHP model.

- Disaggregated nitrogen loadings from atmospheric deposition via the watershed: SPARROW.

- Distribution of developed land in the watershed: USGS National Land Cover Database (NLCD) 2006 Land Cover.

- Precipitation: National Weather Service Forecast Office. Monthly Weather Summary. Providence (TF Green Airport).

OTHER URBAN STORMWATER

In order to capture the effects of low impact development and green infrastructure on nitrogen loadings in the watershed, we designed the nitrogen loadings module in the Narragansett 3VS model so that three source categories – residential fertilizer, atmospheric deposition on developed land, and other urban stormwater – are affected by the amount of impervious surface cover in the watershed. To do so, we created a new category of loadings called "surface water runoff" and estimated nitrogen loadings for this category using the Simple Empirical Method Model (or the "Simple Method"). The Simple Method estimates total surface water runoff loadings as a function of (1) impervious surface area, (2) stormwater runoff pollutant concentrations, and (3) annual precipitation. To estimate total surface water runoff loadings in the Narragansett Bay watershed, we used the Simple Method, together with nitrogen runoff concentration data from the National Stormwater Quality Database, local precipitation data, and local impervious surface area data from USGS GIS datasets for 2002. This estimate of total surface water runoff nitrogen loadings is used in the model in two ways:

1. The Surface Water Runoff category is defined in the model to encompass six other source categories: atmospheric deposition via the watershed on undeveloped land, agricultural fertilizer, animal waste, atmospheric deposition via the watershed on developed land, residential fertilizer, and other urban stormwater (see Exhibit 4-4). As noted in the previous section, we estimate nitrogen loadings in the "other urban stormwater" source category as the difference between total surface water runoff loadings (as estimated using the Simple Method) and all other surface water runoff source categories. For 2002, we estimate that nitrogen loadings from other urban stormwater were 226,311 kg.

2. Of the six source categories that together compose total loadings from surface water runoff, three categories (atmospheric deposition via the watershed on undeveloped land, agricultural fertilizer, and animal waste) originate on undeveloped land, and three categories (atmospheric deposition via the watershed on developed land, residential fertilizer, and other urban stormwater) originate on developed land. Because we assume that changes in impervious cover would primarily take place in developed areas, we designed the model so that changes in impervious cover would affect nitrogen loadings in the "developed land" categories but not the "undeveloped land" categories. As impervious surface area in the watershed increases (due to increased traditional

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development) or decreases (due to low-impact development or green infrastructure), the estimate of total nitrogen loadings from surface water runoff also increases or decreases. The model then adjusts loadings from the three "developed land" categories in proportion to changes in total nitrogen loadings from surface water runoff..

Data sources used for this source category include:

- Simple Method formula for estimating total loadings from surface water runoff: Shaver et. Al (2007), North American Lake Management Society in cooperation with U.S. EPA. Original Simple Empirical Method developed by T. Schueler in 1987 and refined by the Center for Watershed Protection in 2003.

- Nitrogen runoff concentrations: National Stormwater Quality Database (2004), with different values used for open space (0 percent impervious cover) and non-open space (>0 percent impervious cover).

- Precipitation data: National Weather Service Forecast Office. Monthly Weather Summary. Providence (TF Green Airport).

- Impervious cover: USGS National Land Cover Database 2001 Percent Developed Imperviousness Version 2.0.

DISTRIBUTION OF NITROGEN LOADINGS BY REGION AND SEASON

This section describes how we disaggregated total nitrogen loadings to Narragansett Bay, both spatially, in terms of regions of the watershed and bay boxes, and temporally, by season.

SPATIAL DISTRIBUTION

The Narragansett 3VS model distributes loadings spatially in two ways:

1. By region of the watershed: the independent variables used to derive nitrogen loadings by source category (e.g., population, land use) are mostly estimated at the municipal level. Following the method used in the VHP model, we group the municipalities in the Narragansett Bay watershed into eight regions that roughly correspond to subwatersheds within the Narragansett Bay watershed. These regions, or "subwatershed loading areas" are:

    a. Blackstone Above Millville (MA portion)

    b. Blackstone Above Manville (RI portion)

    c. Small Watersheds

    d. Mid/Lower Taunton

    e. Taunton above Bridgewater

    f. Upper Bay

    g. Pawtuxet

    h. Lower Bay

2. By bay box: nitrogen concentrations and related environmental variables are calculated separately by box. We therefore disaggregate nitrogen loadings into the 14 bay boxes for each source

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category.

Exhibit 3-5 presents the subwatershed loading areas and bay boxes on a map of Narragansett Bay and its watershed. Exhibit 3-6 summarizes how we disaggregated nitrogen loadings from each source category by subwatershed loading area and by bay box.

EXHIBIT 3-5. SUBWATERSHED LOADING AREAS AND BAY BOXES USED IN THE NARRAGANSETT 3VS MODEL
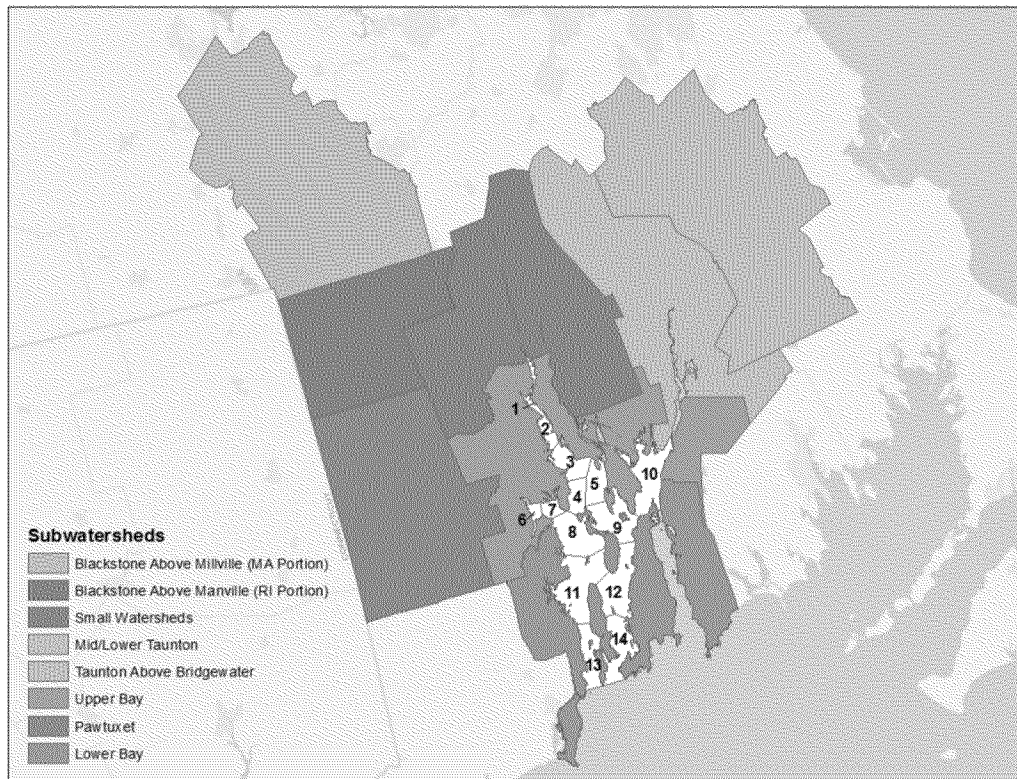
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EXHIBIT 3-6. SUMMARY OF DISAGGREGATION OF NITROGEN LOADINGS BY SUBWATERSHED LOADING AREA AND BY BAY BOX

SOURCE CATEGORY	DISAGGREGATION BY SUBWATERSHED LOADING AREA	DISAGGREGATION BY BAY BOX
WWTFs	We assign loadings from individual WWTFs to the subwatershed loading areas where the facilities are located	We assign loadings from individual WWTFs to the bay box to which they discharge (either directly or via rivers in the watershed)
ISDSs	We estimate the relevant non-sewered population of each subwatershed loading area by multiplying each area's total population by the percent of Rhode Island's population using ISDSs that discharge to the bay. We then multiply that number by the per-capita loading rates for ISDSs.	Using geographic boundaries of subwatersheds within the Narragansett Bay watershed, we developed rough mapping factors to translate loadings by subwatershed loading area into loadings by bay box.
Surface Water Runoff (Total Loadings)	Using the Simple Method, we calculate total surface water runoff loadings, using data on impervious cover for each subwatershed loading area.	As with ISDSs, we used rough mapping factors to translate loadings by subwatershed loading area into loadings by bay box.
Animal Waste	We multiply the animal stock in each subwatershed loading area by loading factors, calibrated to equal total animal waste loadings from SPARROW.	SPARROW provides loadings estimates from animal waste disaggregated by bay box.
Agricultural Fertilizer	We multiply agricultural land in each subwatershed loading area by nitrogen application rates in agricultural fertilizer, adjusted for population and calibrated to equal total agricultural fertilizer loadings from SPARROW.	SPARROW provides loadings estimates from agricultural fertilizer disaggregated by bay box.
Suburban Fertilzer	We multiply the population of each subwatershed loading area by per-capita nitrogen application rates for residential fertilizer, applying a nitrogen transport factor.	We distribute loadings from residential fertilizer by bay box according to the distribution of total surface water runoff loadings.
Atmospheric Deposition via the Watershed (Both Developed and Undeveloped Land)	We multiply deposition rates by land use category-specific nitrogen transport factors, calibrated to equal total atmospheric deposition via the watershed loadings from SPARROW.	SPARROW provides loadings estimates from atmospheric deposition via the watershed disaggregated by bay box.
Other Urban Stormwater	We calculate other urban stormwater loadings for each subwatershed loading area by subtracting loadings from all other surface water runoff source categories from total surface water runoff loadings.	We calculate other urban stormwater loadings for each bay box by subtracting loadings from all other surface water runoff source categories from total surface water runoff loadings.
Atmospheric Deposition Direct to the Bay	Not applicable (deposition direct to the bay does not pass through the watershed)	GIS analysis mapping deposition rates (from CMAQ) to bay boxes

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SEASONAL DISTRIBUTION

Because the risk of nitrogen-induced hypoxia is higher during the summer, and because policies aimed at reducing nitrogen pollution focus on summer loadings, we separated nitrogen loadings into summer and winter seasons to the extent possible. For WWTF loadings, monthly effluent flow and concentration data enabled us to estimate summer and winter loadings for the years 2000 to 2010, as noted above. Agreed-upon effluent limits for selected Rhode Island facilities target summer loadings only, so we reduced summer loadings for these facilities and left winter loadings unchanged. For most other loadings categories, we assume that the flow of nitrogen to Narragansett Bay does not vary significantly by season, with the exception of agricultural and residential fertilizer. Based on the assumption that the majority of fertilization – both of crops and of lawns – occurs during the spring and summer seasons, the model assumes that 80 percent of loadings from agricultural and residential fertilizer occurs during the summer, with 20 percent occurring during the winter.

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SECTION 4 | NITROGEN CONCENTRATIONS

NITROGEN CIRCULATION METHODOLOGY

Our approach to modeling the circulation of nitrogen within Narragansett Bay attempts to remain as faithful as possible to empirical circulation data. We use a spatial disaggregation from the ECOGEM model (Kremer et al. 2010) which divides the bay into 15 segments, or 'boxes.' For the purposes of the Narragansett 3VS model, we opted to remove the Sakkonet river. It is generally viewed as hydrologically distinct from Narragansett Bay since it is connected by only a narrow strait with limited water exchange. We also merged the two boxes that comprise Greenwich Bay, due to lack of sufficiently disaggregated loadings data, yielding a final disaggregation of the bay into 13 distinct boxes (see Exhibit 4-1).

EXHIBIT 4-1. MAP OF BAY BOXES
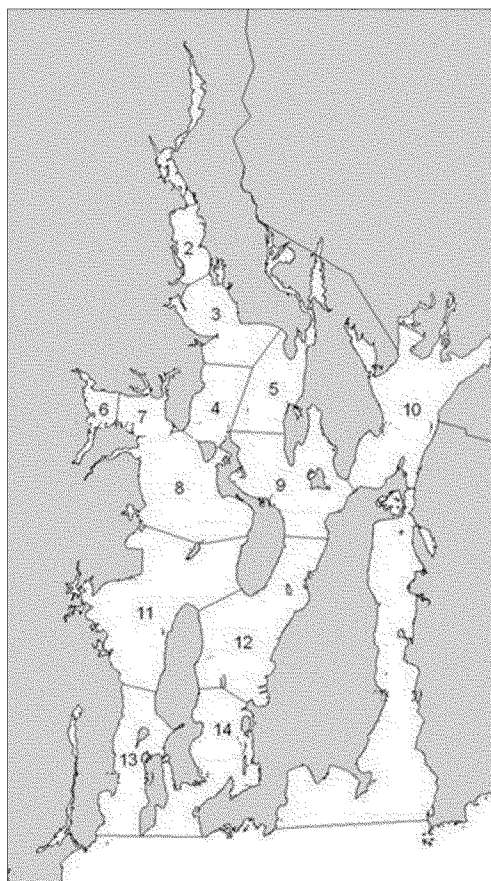
Surface area and volume for each of these boxes were provided by Mark Brush and Jamie Vaudrey (pers. comm.). We decided to use a residence time based approach to model circulation between boxes (with the common assumption of instantaneous mixing within boxes). We estimated residence times for each box based on the work of Abdelrhman (2004) and refined them using a net system water balance approach.

We employ the following simplifying assumptions to model flow. We model only net southward flow in the bay at subtidal frequencies, since we lack appropriate temporal resolution with this model to give reasonable estimates of tidal flow between boxes. We divide flow at the base of the Providence River (Box 3) according to Brush (pers. comm.) with 40% of the flow going into Box 4 and down the West Passage, and 60% of the flow going into Box 5, and down the East Passage. We follow the assumptions of Brush and colleagues (pers. comm.) and disregard lateral flow (e.g. between Boxes 4 and 5, and between Boxes 11 and 12 through the gap between Prudence and Aquidneck Island). Thirty percent of the flow exiting Box 4 is vectored into Greenwich Bay (Boxes 6/7) in line with flow calculations presented by Dimilla et al. (2011), which results in a level of contribution from the bay proper to the overall budget of Greenwich Bay that is roughly consistent with estimates of the relative amounts of nitrogen loading to Greenwich Bay from different sources by Granger (2000) and Urish and Gomez (2004).

In most cases, this modeling approach and current loadings data produced stable steady state

concentrations that closely approximate field observations of nitrogen levels (Krumholz and Oviatt, 2012, Krumholz pers. comm.) for these sections of the bay. In cases where a significant discrepancy between modeled and measured concentration was observed we gave preference to preserving the empirically observed concentration values, and adjusted residence times accordingly. This is the case for Boxes 2, 10, 11, 12 and 13 as presented in Exhibit 4-2. Specifically concerning Box 2, the small volume and high throughput of this box necessitated a modeled residence time of slightly less than half the value calculated by Abdelrhman in order to reconcile inflow and outflow and not result in an unrealistic accumulation of nitrogen in this box.

EXHIBIT 4-2. BAY BOX RESIDENCE TIMES

BAY BOX	LRT OBSERVATIONS (HOURS)	LRT MODEL INPUT (HOURS)
1	67.2	67.2
2	85.0	45.0
3	109.8	109.8
4	132.0	132.0
5	135.0	135.0
Greenwich Bay (6 and 7 combined)	196.8	196.8
8	252.0	252.0
9	130.0	170.0
10	132.0	250.0
11	219.6	350.0
12	262.8	170.0
13	128.4	200.0
14	219.4	219.4

To illustrate the methodology explained above, Exhibits 4-3 and 4-4 present the 3VS module in which N flow is calculated, key equations and sample results of the simulation.

Specifically, Exhibit 4-3 shows a simplified version of the N flow module, with all the inflows and outflows of N for each bay box. This screenshot is simplified, as residence time, initial mass and average water volume were removed to reduce the visual complexity of the sketch.

The area circled in orange is presented in greater detail in Exhibit 4-4, including a list of the seven equations used to estimate the N stock for Box 3 and all its flows, along with graphs showing historical data and simulation results for N concentration in Box 3.

Two graphs are presented for the N concentration in Box 3. A random noise factor is added to match the historical variability observed between 2006 and 2011 (see graph on the left). The graph on the right presents N concentration without the random noise factor, showing concentration as affected by N loadings only.
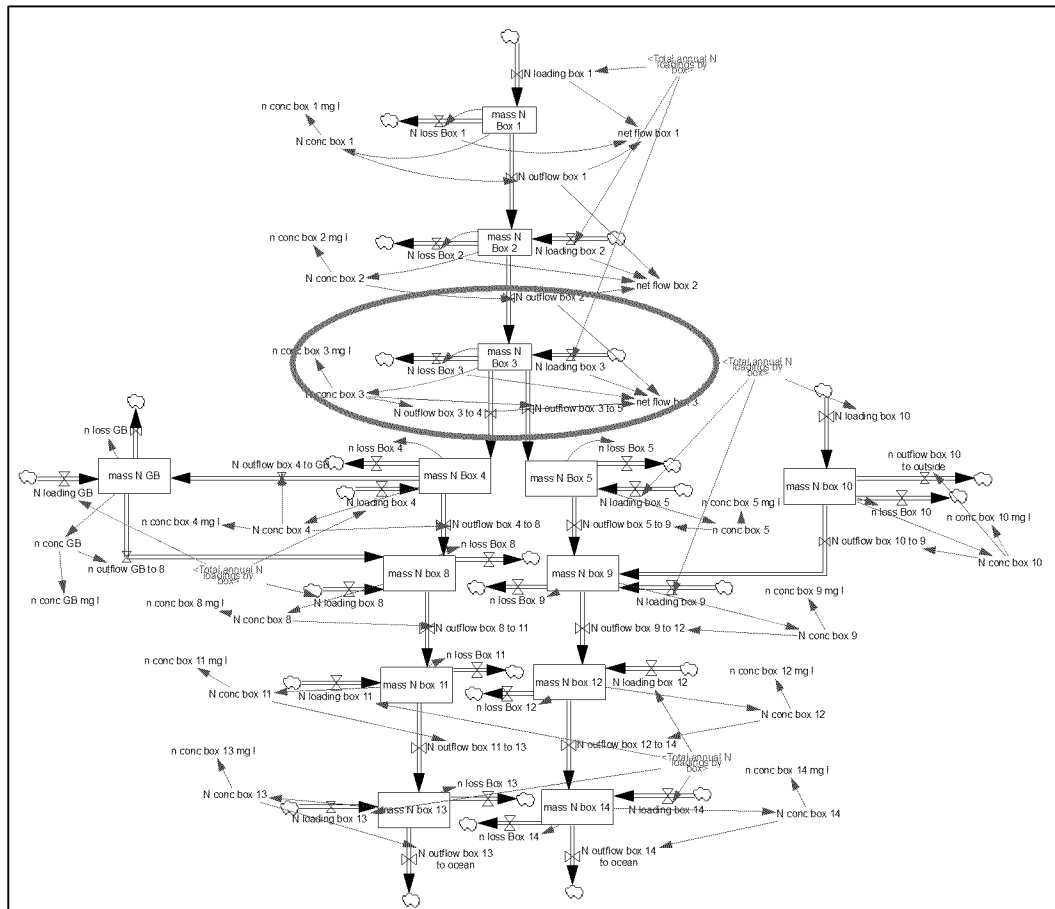
EXHIBIT 4-3. 3VS N FLOW MODULE

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EXHIBIT 4-4.   3VS N FLOW: MODEL, EQUATIONS AND RESULTS
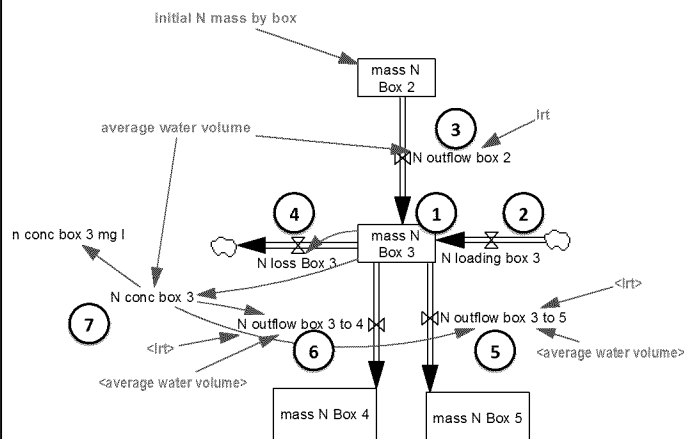
1. **(N stock)** *Mass N Box 3= INTEG (N Loading Box 3+N Outflow Box 2-N Loss Box 3-N Outflow Box 3 To 4-N Outflow Box 3 To 5,Initial N Mass By Box[BOX3])*

2. **(N inflow)** *N Loading Box 3=N Loadings Per Year By Box[BOX3]*

3. **(N inflow)** *N Outflow Box 2= (Average Water Volume[Box2]/Lrt[Box2])*N Conc Box 2*

4. **(N outflow)** *N Loss Box 3= (Mass N Box 3*0.3)*

5. **(N outflow)** *N Outflow Box 3 To 5= (Average Water Volume[Box3]/Lrt[Box3])*N Conc Box 3*0.6*

6. **(N outflow)** *N Outflow Box 3 To 4= (Average Water Volume[Box3]/Lrt[Box3])*N Conc Box 3*0.4*

7. **(N concentration)** *N Conc Box 3= Mass N Box 3/Average Water Volume[BOX3]*

Units: N mass (Kg N), N flows (Kg n/Year), N concentration (Kg/M3, Mg/L).

N concentration, box 3: with random noise (left), without noise (right).

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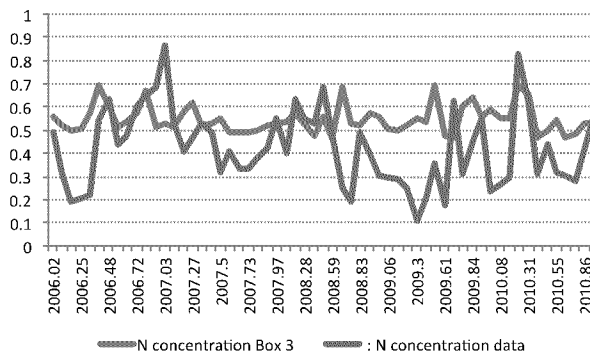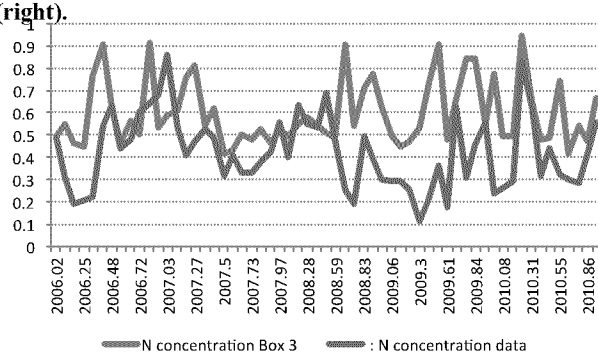
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SECTION 5 | POLICY INTERVENTIONS

This section describes how the Narragansett-3VS model simulates the effects of potential policy interventions aimed at reducing nitrogen loadings to Narragansett Bay. It first defines the model's baseline scenario and then provides additional detail on nine policy interventions that can be run in the model, including eight general interventions and one focused "use case" intervention. For each intervention, we list the category of nitrogen loadings affected and summarize our approach for modeling the impact of each intervention, including nitrogen loadings impacts, costs, and any other variables

GENERAL INTERVENTIONS

BASELINE SCENARIO

The nitrogen loadings that are included in the model's baseline scenario include the current and agreed upon nutrient reductions, with no further actions taken to reduce nitrogen loading. Specifically, nitrogen contributions from WWTFs incorporate facility-specific reductions achieved through 2010, as well as agreed-upon reductions in 2014 for selected plants in Rhode Island. The baseline scenario also includes expected nitrogen removal from Phase I and Phase II of the Narragansett Bay Commission's CSO tunnel.

WASTE WATER TREATMENT FACILITIES (WWTFS)

- Category of nitrogen loadings affected: All loadings from WWTFs in the watershed, with agreed-upon reductions included in the baseline.

- Approach to modeling impact on nitrogen loadings: The user specifies a percent reduction in loadings for all WWTFs in the watershed or in one of the specific subwatershed loadings area. Exhibit 5-1 lists the WWTFs in the Narragansett Bay watershed, noting the subwatershed loading area in which each facility is located, as well as the bay box that receives effluent from each facility.

- Approach to modeling costs and energy use: The user specifies annualized capital costs and operations and management (O&M) costs per unit of nitrogen reduction for all WWTFs in the watershed. The model provides default values of $157.57 per kg N reduced annualized capital costs and $19.64 per kg N reduced for O&M costs. We derived these costs from reports estimating the capital and O&M costs required to meet 8 mg/L and 5 mg/L limits at selected facilities in Massachusetts. The model also includes an assumption that WWTFs will collectively consume an additional kwh of energy for every 25 kg of N reduced. The modeling code can be modified to reflect alternative assumptions about WWTF energy use for N reduction.

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EXHIBIT 5-1. WASTEWATER TREATMENT FACILITIES BY SUBWATERSHED LOADING AREA AND BAY BOX

STATE	WWTF NAME	SUBWATERSHED LOADING AREA	BAY BOX
Rhode Island	Bristol	Upper Bay	9
	Bucklin	Small Watersheds	1
	Burrillville	Blackstone Above Manville (RI Portion)	1
	Cranston	Upper Bay	1
	East Greenwich	Upper Bay	6
	East Providence	Upper Bay	2
	Fields Point	Upper Bay	1
	Jamestown	Upper Bay	14
	Newport	Upper Bay	14
	Quonset	Upper Bay	11
	Smithfield	Small Watersheds	1
	Warren	Upper Bay	5
	Warwick	Pawtuxet	2
	West Warwick	Pawtuxet	2
Massachusetts	Woonsocket	Blackstone Above Manville (RI Portion)	1
	Attleboro	Small Watersheds	1
	Bridgewater	Taunton Above Bridgewater	10
	Brockton	Taunton Above Bridgewater	10
	Douglas	Blackstone Above Millville (MA Portion)	1
	Fall River	Upper Bay	10
	Grafton	Blackstone Above Millville (MA Portion)	1
	Hopedale	Blackstone Above Millville (MA Portion)	1
	Mansfield	Taunton Lower	10
	Middleborough	Taunton Above Bridgewater	10
	North Attleborough	Small Watersheds	1
	Northbridge	Blackstone Above Millville (MA Portion)	1
	Somerset	Taunton Lower	10
	Taunton	Taunton Mid	10
	Upton	Blackstone Above Millville (MA Portion)	1
	Uxbridge	Blackstone Above Millville (MA Portion)	1
	Worcester / Upper Blackstone Water Pollution Abatement District	Blackstone Above Millville (MA Portion)	1

INDEPENDENT SEWAGE DISPOSAL SYSTEM (ISDS) UPGRADES

- <u>Category of nitrogen loadings affected</u>: All loadings from ISDSs within the watershed boundary that are expected to send nitrogen to the Bay, defined by those located on soils with high infiltration rates that are connected to the Bay or that overlap rivers and streams leading to the Bay.

- <u>Approach to modeling impact on nitrogen loadings</u>: The user species the percentage of ISDSs to be upgraded for the whole watershed. We estimate that upgraded ISDSs remove 20% of the

baseline per-person nitrogen (4.4 kg/yr). The modeling code can be modified to reflect alternative estimates of ISDS N removal effectiveness.

- Approach to modeling costs: Total costs of upgrading the systems are estimated to be $10,000 per household. The user can specify a different cost for ISDS upgrades.

ANIMAL WASTE REDUCTIONS

- Category of nitrogen loadings affected: Total loadings from animal waste.

- Approach to modeling impact on nitrogen loadings: The user specifies a percent reduction in loadings from animal waste for the whole watershed.

- Approach to modeling costs: The user specifies costs per kg of nitrogen loadings reduced.

AGRICULTURAL FERTILIZER USE REDUCTIONS

- Category of nitrogen loadings affected: Total loadings from agricultural fertilizer use.

- Approach to modeling impact on nitrogen loadings: The user specifies a percent reduction in loadings from fertilizer use across the watershed.

- Approach to modeling costs: The user specifies costs per kg of nitrogen loadings reduced.

RESIDENTIAL FERTILIZER USE REDUCTIONS

- Category of nitrogen loadings affected: Total loadings from residential fertilizer use.

- Approach to modeling impact on nitrogen loadings: The user specifies a percent reduction in loadings from fertilizer use for each subwatershed loading area.

- Approach to modeling costs: The user specifies costs per unit of nitrogen loadings reduction.

OYSTER AQUACULTURE

- Category of nitrogen loadings affected: This is a "what if" scenario that shows the potential nitrogen removal of 20 one-acre aquaculture farms in the Upper Bay. The aquaculture scenario assumes that these aquaculture farms are introduced to areas of the Bay that are designated by RIDEM as "Conditional" areas or "Approved" areas for shellfishing. We assume that each farm is 1 acre in size and produces 100,000 oysters annually after a 2 year start-up period (CRMC 2011; RIDEM 2013; N. Thompson, personal communication on June 2012).

- Approach to modeling impact on nitrogen loadings: We estimate the amount of nitrogen removed through bioharvesting and bioremediation of 100,000 oysters for each of the 20 farms. The user can specify how many farms are established in each bay box. We estimate that the total nitrogen removed per farm is approximately 677 lbs/year (M. Rice, personal communication on September 5, 2012; Newell et al., 2005). We recognize that research is currently being conducted to determine the extent of nitrogen removal by shellfish, and that therefore these estimates may need to be revised in future versions of the model. Note that the modeling code can be modified to reflect alternative values for these inputs.

- Approach to modeling costs and other impacts: We estimate annual operating costs of $10,000 per farm (N. Thompson, personal communication on June 2012). We estimate annual revenues of approximately $57,200 per farm (CRMC 2011). We also estimate that each farm employs 2

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people (CRMC 2011). Note that the modeling code can be modified to reflect alternative values for these inputs.

ATMOSPHERIC DEPOSITION REDUCTIONS

- Category of nitrogen loadings affected: Loadings from atmospheric deposition direct to the bay and via the watershed on developed and undeveloped land.

- Approach to modeling impact on nitrogen loadings: As part of the baseline scenario, the model incorporates predicted decreases in atmospheric deposition from national and regional air pollution reduction programs through 2020. These decreases result in a reduction atmospheric deposition of nitrogen, both direct to the bay and on the watershed. The user can specify an additional reduction in loadings from air deposition for the whole watershed beyond those associated with existing programs.

- Approach to modeling costs: The model currently does not include costs for atmospheric deposition reductions. Future versions of the model can incorporate a feature to allow users to specify costs for this policy intervention.

LID/GI (GENERAL)

- Category of nitrogen loadings affected: Loadings from surface water runoff on developed land, i.e., residential fertilizer, atmospheric deposition via the watershed, and other urban stormwater.

- Approach to modeling impact on nitrogen loadings: The user specifies the percent of each subwatershed loading area that is covered with impervious surface. The model uses percent impervious cover to calculate total loadings from surface water runoff, which includes agricultural and residential fertilizer, animal waste, atmospheric deposition via the watershed on both developed and undeveloped land, and other urban stormwater. We assume, however, that changes in impervious cover primarily take place on developed land. As a result, any changes in nitrogen loadings due to increases or decreases in impervious cover are distributed among the three surface water runoff loadings categories listed above.

- Approach to modeling costs: The user specifies costs per kg of nitrogen loadings reduced.

TARGETED USE CASE INTERVENTION

LID/GI (USE CASE)

- Category of nitrogen loadings affected: Loadings from surface water runoff on developed land, i.e., residential fertilizer, atmospheric deposition via the watershed, and other urban stormwater. This intervention only affects loadings for the two Use Case areas, i.e., the Taunton watershed and the municipalities surrounding Providence.

- Approach to modeling impact on nitrogen loadings and property values: The approach for modeling impacts of LID/GI on nitrogen loadings in the LID/GI Use Case intervention is similar to the approach for the general intervention, with one exception: the user can specify both the percent impervious surface cover for both the baseline scenario and the LID/GI policy implementation scenario. For the two Use Case areas, the model uses projected increases in imperviousness from the Integrated Climate and Land Use Scenarios (ICLUS) model. The Use Case also shows the impact of LID/GI implementation on property values in these two regions, as

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described in greater detail in Section 6.

- <u>Approach to modeling costs</u>: The LID/GI Use Case assumes that implementing LID/GI for new development (i.e., preventing any increase in percent impervious cover) has no cost. For LID/GI retrofits (i.e., reducing percent impervious cover below initial values), the user specifies costs per acre of impervious area reduced. The user can specify a curve of costs, so that as more impervious cover is reduced, the cost per acre increases.

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SECTION 6 | MODELED RELATIONSHIPS

This section describes the data that were used to develop environmental and socioeconomic relationships in the Narragansett-3VS model. It explains the derivation of the relationships used in the model to show the effects of nitrogen loading on environmental, social, and economic indicators.

DERIVATION OF ENVIRONMENTAL RELATIONSHIPS

This section presents the results of our efforts to compile data on the effects of nitrogen loading on environmental indicators. To accomplish this, we reviewed existing literature and contacted a number of local scientists who have conducted studies of the environmental conditions in the Bay.

The relationships outlined here have been incorporated into the Narragansett-3VS model and serve as the basis for estimating outcomes caused by baseline nitrogen loadings and changes in loadings over time.

NITROGEN LOSSES IN THE BAY

This relationship simplifies nitrogen loss as a simple function of nitrogen stock. Nitrogen loss occurs through sedimentation, denitrifiation and other nitrogen process that vary throughout the bay in space and time.

Relationship:

> *Nitrogen loss* (kg N/year) = *.3 * Nitrogen stock* (kg N/year)

Source: Ed Dettmann, personal correspondence.

EFFECT OF NITROGEN LOADING ON CHLOROPHYLL A

The relationship between nitrogen loading and Chlorophyll A is specific to Narragansett Bay and was developed and published by Ed Dettmann of the EPA Atlantic Ecology Lab. The relationship is based on regression analysis of data from Narragansett Bay.

Relationship:

> Summer: *Chlorophyll a (μg / L) = 57.5 * (N concentration in water (g / m^3)) ^2.09*

> Winter: *Chlorophyll a (μg / L) = 10.3 * (N concentration in water (g / m^3)) ^1.275*

Source: Dettmann et al. (2005).

EFFECT OF NITROGEN LOADING ON RELATIVE SEA LETTUCE (ULVA) GROWTH RATE

The estimate of the daily growth rate of ulva is derived from Figure 3 in Teichberg et al. 2010, which represents average daily growth rates of ulva in controlled settings during peak growing season. The regression line is interpreted to be equal to the following:

> *Daily growth rate (%) = (Log(annual dissolved inorganic nitrogen concentration (μM)) * 9)/100*

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Annual dissolved inorganic nitrogen concentration (μM) is converted to (g N / m^3) by multiplying by *0.014*. By the properties of logarithms, adding *Log(0.014)*9/100*, or *16.685/100* preserves the original relationship when nitrogen is measured in grams per cubic meter.

Relationship:

Percentage growth of ulva per day = ((Log(N (g / m^3)) * 9 + 16.685)) / 100

Source: Calculations from Teichberg et al. (2010).

EFFECT OF MICRO ALGAE (CHLOROPHYLL A) ON SECCHI DEPTH

Secchi depth is estimated from Chlorophyll A by a linear relationship with Chlorophyll A and a Chlorophyll A quadratic term. Chlorophyll A is measured as the maximum level of the three measures taken at each station (surface, middle or bottom). Increases in Chlorophyll A decrease Secchi depth with a diminishing effect until Secchi depth reaches 0.5 meters. Minimum Secchi depth is set to 0.5 meters to reflect observed conditions in the Bay and the limits of the impact of Chlorophyll A on Secchi depth. The regression is conducted using Stata V.12 with 98 observations and R^2 of 0.214. All coefficients are significant at the one percent level.

Relationship:

Secchi depth (meters) = 2.83 - 0.09*(Chl A (μg / L)) + 0.000776 * (Chl A (μg / L))^2,

if 0 < Chl A (μg / L) <= 39;

Otherwise Secchi depth (meters) = 0.5

Source: Regression analysis of Narragansett Bay data from the *NOAA National Coastal Assessment Northeast Database: Years 2000 to 2006*. Data and Stata ".do" files available upon request.

EELGRASS IMPROVEMENT POTENTIAL

The metric of eel grass improvement potential includes two parts. One, the bay boxes are categorized into three bins based on the relative area of suitable and very suitable eelgrass area as defined by the 2003 Rhode Island Eelgrass Transplant Suitability analysis. These suitable and very suitable eel grass areas are believed to benefit from increased Secchi depth. The bins are valued at one, two or three, based on increasing suitable eelgrass transplant area. Two, the estimated Secchi depth of the bay box is grouped into three bins. The bins are valued at one, two or three, based on increasing Secchi depths.

The Rhode Island Eelgrass Transplant Suitability Index examines bathymetry, temperature, light, current eelgrass, and historic eel grass. Bathymetry and temperature are used to determine if the area could support eelgrass transplants. Areas with current eelgrass are excluded. Light extinction data are scaled from zero to two, with increases in light penetration resulting in higher scores. Areas known to historically support eel grass are scored as two and one otherwise. The acres of suitable and very suitable eel grass areas are presented by bay box below in Exhibit 7-1:

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EXHIBIT 6-1. EEL GRASS AREA BY BAY BOX

BAY BOX	ACRES OF SUITABLE AND VERY SUITABLE EELGRASS TRANSPLANT HABITAT
1	63
2	223
3	560
4	35
5	119
6&7	454
8	176
9	255
10	375
11	111
12	86
13	73
14	63

Since the suitable transplant area excludes current eelgrass areas, the model does not suggest areas where decreased light conditions would harm the eelgrass. As the focus of the 3VS approach is on interventions that improve the health of the Bay, the transplant suitability data are appropriate for the model purposes. These data allow the model to use the wealth of primary research on areas that would benefit from increased light penetration incorporated in the Rhode Island Eelgrass Transplant Suitability Index.

Relationship:

Relative area of eelgrass transplant suitability is the first factor in the metric as shown in Exhibit 7-2:

EXHIBIT 6-2. RELATIVE AREA OF EELGRASS TRANSPLANT SUITABILITY

RELATIVE AREA OF EELGRASS TRANSPLANT SUITABILITY	BAY BOXES	ASSIGNED VALUE
Low	1, 4, 12, 13, 14	1
Medium	2, 5, 8, 11	2
High	3, 6 & 7, 9, 10	3

Changes in Secchi depth in each box is the second factor in the metric as shown in Exhibit 6-3:

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EXHIBIT 6-3.   RELATIVE SECCHI DEPTH

RELATIVE SECCHI DEPTH	SECCHI DEPTH VALUES	ASSIGNED VALUE
Low	0.5 to 1.2	1
Medium	1.2 to 1.9	2
High	1.9 to 2.83	3

Multiplying these factors creates the eelgrass metric as shown in Exhibit 6-4:

EXHIBIT 6-4.   EELGRASS METRIC

PRODUCT OF ASSIGNED VALUES	CATEGORY	INTERIM METRIC COMBINATIONS
1, 2	Low potential for eelgrass improvement	• Low area and low light • Medium area/light with low area/light
3, 4	Medium potential for eelgrass improvement	• High area/light with low area/light • Medium area with medium light
6, 9	High potential for eelgrass improvement	• Medium area/light with high area/light • High area and high light.

Sources: Short, F., Burdick, D., and J. Kaldy. (1995); 2003 Rhode Island Eelgrass Transplant Suitability Metadata. Available at: http://www.narrbay.org/d_downloads/D_Biological/D_habitat/eelgrtrans.htm

HYPOXIA RISK

The creation of hypoxia in the Bay is complex process. This qualitative index seeks to represent the following three known risk factors of hypoxia:

- Chl A - . Increased levels of Chl A in summer months are commonly believed contribute to hypoxia risks.

- Precipitation - Higher levels of precipitation may lead to greater stratification in the Bay, contributing to the creation of hypoxia.

- Location in the Bay - Different areas of the bay based on their specific geophysical characteristics are differentially prone to hypoxia.

The qualitative index ranks each box using these risk factors to suggest the potential risk of hypoxia during the summer season.

Relationship: The relationship is presented in Exhibits 6-5. And 6-6

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EXHIBIT 6-5. HYPOXIA RISK METRIC COMPONENTS

COMPONENT RISK LEVEL (POINTS)	CHL A JUNE - AUG AVERAGE (µg/l)	BOX RISK (BY BOX NUMBER)	JUNE - AUG PRECIP (INCHES)
High (3)	>20	1, 2, 3, 6, 7	>13
Medium (2)	>5, ≤ 20	8, 4, 5, 9, 10	>9, ≤ 13
Low (1)	>0, ≤ 5	11, 12, 13, 14	≤9

EXHIBIT 6-6. HYPOXIA RISK METRIC SCORING

TOTAL RISK LEVEL	SUM OF POINTS	INTERIM METRIC COMBINATIONS
High	8, 9	• All high risk factors (9) • Two high risk factors and one medium risk factor (8)
Medium	6, 7	• Two medium risk factors and one high risk factor (7) • Two high risk factors and one low risk factor (7) • One each high, medium, and low risk factors (6) • Three medium risk factors (6)
Low	3, 4, 5	• Two low risk factors and one high risk factor (5) • Two medium risk factors and one low risk factor (5) • Two low risk factors and one medium risk factor (4) • All low risk factors (3)

Sources: Bricker et al. 2003, precipitation data from TF Green airport available upon request.

FIN FISH LANDINGS

The commercial fin fish landings are modeled using an empirical relationship between finfish abundance and nitrogen loadings from Figure 3 in Brietburg et al. 2009. Brietburg et al. 2009 estimates the relationship between nitrogen loadings and fisheries landings of mobile species in estuaries and semi-enclosed seas from sites across the globe.

The modeled relationship is an inverted "U" shape and local experts debate where on this curve the Bay is located (i.e., would decreasing nitrogen concentrations cause improvement or decline in fisheries landings). The model predicts that at current levels of nitrogen loading, increased loading will decrease commercial fin fish landings according to the relationship presented below.

The 3VS model uses this relationship to calculate the relative change in the commercial landings from baseline values conditions and applies this to estimates of commercial finfish caught in Narragansett Bay.

Baseline commercial fish landings data (pounds and dollar value) are obtained from the RIDEM Standard Atlantic Fisheries Information System (SAFIS) Dealer Reports for 2010. An estimated 5% of statewide

finfish catch comes from the Bay, based on Tyrell, Devitt and Smith (1994) and personal communication with John Scotti, Senior Fisheries Specialist at Cornell University (2012), and Phil Colarusso, Ocean and Coastal Protection Unit USEPA Region I (2012). Using these figures, baseline commercial finfish value caught in Narragansett Bay is estimated at 2,140,519 pounds and valued at $1,150,676. The model expresses the change in fish landings in terms of dollar value of catch.

Relationship:

> *where x is the log annual nitrogen loadings in $\log_{10}kg\ km^{-2}\ year^{-1}$*
>
> *and f is fisheries landings in log ($kg\ km^{-2}\ year^{-1}$)*

Sources: Brietburg et al. (2009); Tyrell et al. (1994); John Scotti, personal communication (2012); and Phil Colarusso, personal communication (2012)

SOCIOECONOMIC INDICATORS AND RELATIONSHIPS

Much of the demographic and socioeconomic data used in the model comes from the National Oceanic and Atmospheric Administration's (NOAA) Spatial Trends in Coastal Socioeconomics (STICS) database. This database, maintained by NOAA's National Ocean Service Special Projects Office, provides data for EPA's National Estuary Program watersheds, including the Narragansett Bay watershed. Data are available for 42 demographic variables, including population, employment, and labor force, for every five years from 1970 to 2040.

BEACH VISITS

The Narragansett 3VS model includes visitation data for seven beaches located within the study area (see Exhibit 6-7): Barrington Town Beach and Conimicut Point Beach (Box 4), City Park Beach and Goddard Park Beach (Box 6), Gorton's Pond and Oakland Beach (Box 7), and Narragansett Town Beach (Box 13) (Marisa Mazzotta, personal communication May 2, 2012). We did not include visitation data for state beaches in the model, as these beaches are located along the coast outside of the Bay.

EXHIBIT 6-7. BEACHES WITH VISITATION DATA INCLUDED IN THE NARRAGANSETT 3VS MODEL

BEACH	GENERAL AREA	CORRESPONDING BAY BOX	ANNUAL VISITATION (NUMBER OF VISITS)
Barrington Town Beach	Upper Bay	4	3,280
Conimicut Point	Upper Bay	4	2,575
City Park Beach	Greenwich Bay	6	4,600
Goddard Park Beach	Greenwich Bay	6	221,536
Gorton's Pond	Greenwich Bay	7	810
Oakland	Greenwich Bay	7	11,400

| Narragansett Town Beach | Lower Bay | 13 | 425,393 |

Based on the results of a doctoral dissertation on the Peconic Bay (Diamantides, 2000), we estimate that a one percent change in water clarity depth (Secchi depth) translates into a 0.56 percent change in the number of beach visits. To determine the economic impacts of the resulting change in beach visits, we examine the consumer surplus per beach visit, which is a measure of the direct benefit to the visitor. We estimate that the consumer surplus per visit is $7.74 (USD 2011), based on a Peconic Estuary recreation survey conducted in 1995 and a 1998 study by Kline and Swallow (Opaluch et al., 1999; Kline and Swallow, 1998).

PROPERTY VALUE

General

We have estimated a relationship between changes in water clarity and property value based on three studies that provide estimates of the percent change in property value for waterfront properties resulting from changes in Secchi depth (Gibbs et al., 2002; Walsh, Milon and Scrogin, 2010; and Boyle et al., 1998). Based on these studies, we estimate that a one meter increase in Secchi depth results in a 3% increase in property value.

For the model, we estimate waterfront residential property values for the Bay using 2011 American Community Survey Census data which provides median property values for owner-occupied residential structures in block groups adjacent to the Bay (U.S. Census Bureau, 2011). We provide aggregate property values at the subwatershed loading area level for use in the model, which are calculated using the median property values for the block groups in the subwatershed loading areas, multiplied by the total number of owner-occupied residential structures. Because property value data from the Census is self-reported by owners of owner-occupied structures, the values may be somewhat overstated. Conversely, the exclusion of non-owner occupied structures from this data set, likely results in an underestimate of aggregate property value within the block groups. In addition, note that commercial properties are not included in this relationship, which also results in an underestimate of total property value impacts.

LID/GI Use Case

For the LID/GI Use Case areas – the Taunton watershed and Providence and surrounding municipalities – we model the effect of LID/GI on property values. A meta-analysis conducted by EPA suggests that an increase in open space in new development increases the property value of new units, and – to a lesser extent – of existing units. The ICLUS projections that provided us with estimates of increased impervious cover in the baseline scenario for the two Use Case areas also provided projections of increased housing density, which we used to estimate the number of new units in each area. We assume that LID/GI that reduces impervious cover below baseline values also increases the amount of open space around new and existing units. Using regression parameters from EPA's analysis (provided by Mazzotta, 2013), we relate changes in percent impervious cover to increases in property value for new and existing units. This relationship depends on a number of assumptions that the user can adjust, including:

- The percent of LID/GI that involves increased open space surrounding new units (default value: 100 percent)

- The maximum increase in open space that can be implemented surrounding new units (default value: 10 percent)

- The percent of existing units that have new open space within a 500-meter radius (default value: 100 percent).

GDP

GDP is calculated using a supply side approach (extended Cobb-Douglas production function), while ensuring macroeconomic consistency by tracking the demand side of the equation (GDP = consumption + investment + government spending + net export). The main factors used to calculate GDP are capital (an accumulation of investment), labor and productivity. GDP for the primary sector includes agriculture (crop production), livestock, fishery and forestry. GDP for the services sector includes consumer surplus of tourism expenditure. GDP is estimated for the whole Narragansett Bay, using average per capita economic data (State Accounting) from Rhode Island and Massachusetts.

PER CAPITA DISPOSABLE INCOME

Household income is calculated by subtracting taxation from total household revenues (calculated by summing up GDP and all the additional monetary flows from the public to the private sector, e.g. private transfers and debt interest payment). The calculation of household accounts is defined in the System of National Accounts (SNA) and the Social Accounting Matrix (SAM) that are also applied at the State level.

MUNICIPAL TAX REVENUE

The calculation of the municipal tax uses a 1.52% tax rate, which is multiplied by the value of owner occupied structures in the Bay. This value is assumed to be affected by water clarity. This tax revenue (approximately $540 million) is compared with total government revenue estimated for Narragansett Bay (approximately $20 billion).

ENERGY USE

Energy demand is estimated using four main drivers: GDP, population, energy prices and technology (energy efficiency). Changes in these four drivers are reflected in energy demand using elasticity factors to represent the strength of each specific causal relation. In particular, GDP and population have a positive causal relation with energy demand, while energy prices and technology have a negative causal relation with energy demand.

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SECTION 7 | SUMMARY OF ADDITIONAL RESEARCH

This section summarizes additional research that we conducted as we developed the Narragansett 3VS model. As noted in Section 2, there are several aspects of the Narragansett Bay system that we were not able to include in the model. The research presented in this section includes additional information related to the data sources that we used to develop the model, other models that indirectly guided the development of the Narragansett-3VS model, data sources that could contribute to future versions of the model, and data sources that we determined did not fit the scale and scope of this model. Exhibit 7-1 presents additional research conducted for environmental relationships. Exhibit 7-2 lists information on research conducted for social and economic relationships. Exhibits 7-3 and 7-4 present information on research conducted into low impact development and green infrastructure. Exhibit 7-3 summarizes data sources that could potentially be usable for future development of the model, while Exhibit 7-4 summarizes data sources that we determined were not applicable for the Narragansett-3VS model.

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EXHIBIT 7-1. SUMMARY OF ADDITIONAL RESEARCH INTO ENVIRONMENTAL RELATIONSHIPS

TOPIC	SOURCE	SUMMARY
Circulation	Dettmann, E.H. 2001. Effect of Water Residence Time on Annual Export and Denitrification of Nitrogen in Estuaries: A Model Analysis. *Estuaries*, Vol. 24, No. 4., p. 481-490. August.	This source provides background information on residence time and denitrification for 11 estuaries across the world, including Narragansett Bay. As noted in the environmental relationships section, the model uses a source more specific to Narragansett Bay (Abdelrhman 2005) for residence time. Also noted in the environmental relationships section, Ed Dettmann, USEPA Atlantic Ecology Division, provided a denitrification coefficient of 30 percent annually for Narragansett Bay.
Circulation	Hill, B.H., Bolgrien, D.W. 2010. Nitrogen Removal by Streams and Rivers of the Upper Mississippi River Basin. *Biogeochemistry*. doi: 10.1007/s10533-010-9431-8. April.	This source provides background information on nitrogen in streams and rivers, which is not included in the model, but may be useful in modeling efforts that focus more on river and stream environments.
Circulation	Kellogg, D.Q. et al. 2010. A Geospatial Approach for Assessing Denitrification Sinks Within Lower-Order Catchments. doi: 10.1016/j.ecoleng.02.006. *Ecological Engineering*.	This source provides background information on denitrification processes. As noted in the environmental relationships section, Ed Dettmann, USEPA Atlantic Ecology Division, provided a denitrification coefficient of 30 percent annually for Narragansett Bay, which is used in the current version of the model.
Circulation	Vaudrey, J.M.P., Kremer, J.N. Narragansett Bay EcoGEM Model, 2006. V. 10.21.11. Department of Marine Science, University of Connecticut. Funded by Coastal Hypoxia Research Program, National Oceanic and Atmospheric Administration "Modeling Tools to Understand and Manage Hypoxia: Application to Narragansett Bay. Grant NA05NOS4781201.	This source provides background information on circulation models for Narragansett Bay.
Eelgrass	Thursby, Glen. United States Environmental Protection Agency – Atlantic Ecology Division, Personal Communication. 2012	Dr. Thursby discussed the possibility of using Secchi depth to determine light extinction coefficient, but this approach was not directly applicable to the model because of insufficiently detailed bathymetry and Secchi depth data. However, the fundamentals of these relationships have been incorporated into the qualitative eel grass metric. Future versions of the model may benefit from Dr. Thursby's bio-optical model.
Eelgrass	Latimer, J and S. Rego. 2010. Empirical Relationship between eelgrass extent and predicted watershed-derived nitrogen loading for shallow New England estuaries. Estuarine, Coastal and Shelf Science 90 p. 231-240.	This source provides information on the effect of nitrogen loadings on eelgrass habitat. In developing the Narragansett 3VS model we chose to focus environmental impacts on changes in nitrogen concentration where possible to allow for disaggregation by bay box.

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Hypoxia	Codiga, D., Stoffel, H., Deacutis, C., Kiernan, S., and C. Oviatt. 2009. Narragansett Bay Hypoxic Event Characteristics Based on Fixed-Site Monitoring Network Time Series: Intermittency, Geographic Distribution, Spatial Synchronicity, and Interannual Variability. Coastal and Estuarine Research Federation. Published online: May 23. Deacutis, C.F., D. Murray, W. Prell, E. Saarman, L. Korhun. 2006. Hypoxia in the Upper Half of Narragansett Bay, RI, During August 2001 and 2002. Northeastern Naturalist Vol 13, pp. 173-198. Melrose, D.C., Oviatt, C.A., and Berman, M.S. 2007. Hypoxic Events in Narragansett Bay, Rhode Island, during the Summer of 2001. Estuaries and Coasts, vol. 30, no. 1, pp. 47-53.	These sources provide additional background on hypoxia in Narragansett Bay.
Shellfish Growth Rate	Weiss et al. 2002. The effect of nitrogen loading on the growth rates of quahogs (Mercenaria mercenaria) and soft-shell clams (Mya arenaria) through changes in food supply. Aquaculture Vol. 211, pp. 275-289.	In developing the 3VS model, we explored including a relationship between nitrogen loadings and shellfish growth rate. However, the available data on this relationship did not appear to capture the full range of effects of nitrogen loading on growth rate.

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EXHIBIT 7-2. SUMMARY OF ADDITIONAL RESEARCH INTO SOCIAL AND ECONOMIC RELATIONSHIPS

TOPIC	SOURCE	SUMMARY
Beaches	Rhode Island Department of Health, Beach Program http://www.health.ri.gov/beaches/	Rhode Island Department of Health collects data on beach closures and water quality for 114 licensed facilities (72 licensed saltwater beaches and 42 licensed freshwater beaches). In addition, a small number of unlicensed beaches were sampled for the first time in 2011. Sampling frequencies range from once a week to once a year depending on the history of individual beaches, and some beaches are exempt from sampling. These data are not currently incorporated into the model because beach closures are driven by pathogen loadings rather than nitrogen loadings; however, should future versions of the model incorporate data on pathogen loadings, it may be desirable to model beach closures. In addition, the Department of Health may be able to provide information on health-related impacts associated with pathogen loadings.
Property Value	Poor, P. Joan, KL Pessagno, RW Paul. Exploring the hedonic value of ambient water quality: A local watershed based study. Ecological Economics, 2007, vol. 60, issue 4, pages 797-806.	This is a hedonic analysis of the impact of ambient water quality in the St. Mary's River watershed (located in southern Maryland) on residential property sales throughout a watershed. The specific water quality measures considered are total suspended solids (TSS) and dissolved inorganic nitrogen (DIN). The study finds that a 1 mg/L change in ambient inorganic nitrogen changes property values by 8.8 percent, averaged over properties both on the waterfront and further away from the water. We did not use this relationship for the model because the water quality samples used for this study came mostly from small streams within the watershed. For Narragansett, our focus was on nitrogen concentrations within the Bay, not within streams in the surrounding watershed.
Property Value	Langworthy, Malia K. 2007. Open Space Financing in Seattle: A Closer Look at the Effects of Open Space on Property Values, City Revenues and Housing Affordability. University of Washington.	This paper examines the relationship between proximity to urban parks and the financial return to property owners, developers, and the public in the form of higher property values, especially in dense urban areas. The paper explores how open space (mainly urban parks) cause property values to rise and in turn displace low-income residents and negatively impact housing affordability. We determined that the Gibbs et al.; Walsh, Milon, and Scrogin; and Boyle et al. studies were better suited for the Narragansett 3VS model due to the fact that this study is more focused on how urban parks affect housing affordability.

Tourism	Hayes, Karen M., Timothy J. Tyrrell, Glen Anderson. "Estimating the Benefits of Water Quality Improvements in the Upper Narragansett Bay." Marine Resource Economics 7 (1992): 75-85.	This study involved a water quality survey designed to obtain information about the value Rhode Island residents place on improved water quality in the Bay. The study used the contingent valuation approach and responses from 435 residents to a 1985 survey about how they would value two water quality changes -- improvements to allow safe swimming and improvements to allow shellfishing in the Upper Bay. The survey was conducted in 1985, so we felt that the results were too dated to be used in the model. In addition, we were not able to develop quantitative relationships between N concentrations and safe swimming and shellfishing in the Upper Bay; these activities are more directly affected by loadings of pathogens rather than nitrogen.
Tourism	Tyrrell, Timothy J., Maureen F. Devitt, and Lynn A. Smith. The Economic Importance of Narragansett Bay. Final Report Prepared for: The Rhode Island Department of Environmental Management – Narragansett Bay Project and The Rhode Island Sea Grant College Program. November 4, 1994.	This study provides value estimates for Bay-related industry jobs and wages; Bay-related tourism jobs, wages, and revenues; revenues for commercial fish catch from the Bay; total property value in Bay communities; Bay recreation-related visitors, revenues, jobs, wages, and expenditures; State-wide recreational fishing trips and related expenditures; and the budget for research and regulation of the Bay. Because the data were collected in 1994, we felt that the data were too dated to be used in the model. In addition, a relationship between nitrogen concentration and tourism would need to be established before these data could be used in the model.
Tourism	Colt, Ames, Timothy Tyrrell, and Virginia Lee. Narragansett Bay Summit 2000 White Paper. Marine Recreation and Tourism in Narragansett Bay: Critical Values and Concerns. Working Draft. April 11, 2000.	This study provides statewide sales revenues from travelers and tourists, and associated wages and jobs. It provides an estimate of total annual Bay-related outdoor recreation activities ($2 billion). The study cites results of Tyrrell, Devitt and Smith's 1994 study "The Economic Importance of Narragansett Bay" for estimates of the Bay's contribution to tourism revenues. It provides net willingness to pay for marine-based outdoor recreation, average yachting event expenditures, recreational fishing expenditures (all statewide, not Bay-specific). It also provides a qualitative discussion of the economic, social, and environmental effects of tourism and recreation. In order for this information to be used in the model, we would need to establish a relationship between nitrogen concentration and tourism.
Tourism	Pacheco, Andrada I., and Timothy J. Tyrrell. The Economic Value of Narragansett Bay: A Review of Economic Studies. March 2003.	This is a review of studies estimating values of the Narragansett Bay ecosystem which cites findings from Tyrrell and Harrison (2000) for the value of ecosystem services in the Bay ($2 billion in 1994 dollars). It provides summary tables listing the findings of various studies related to ecosystem services – including the value of raw materials, food production, recreation, cultural, industrial and commercial services of the Bay. In order to use these values in the model, we would need to establish a relationship between nitrogen concentration and the ecosystem services valued.

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Tourism	Tyrrell, Timothy J. Rhode Island Travel and Tourism Research Report. University of Rhode Island, Department of Resource Economics. Volume 22, Number 1. April 2005.	Provides statewide data on the travel and tourism economy. Also provides city and town level data on tourism industry wages and output. In order to use these values in the model, we would need to establish a relationship between nitrogen concentration and tourism.
Tourism	National Coastal Condition Report III, Chapter 9: Health of Narragansett Bay for Human Use. December 2008.	Provides a variety of tourism-related data for the Bay, including beach closures data (same data as on the RIDEM Beaches website); the number of registered boats in Rhode Island in 2002; and the annual commercial fish catch (statewide) and estimates for the lobster and quahog catch from the Bay (we use more updated data on for commercial fish landings in the model than what are provided here). In order for these data on tourism to be used in the model, we would need to establish a relationship between nitrogen and tourism.
Tourism	Hellin D, Starbuck K, Terkla D, Roman A and Watson C (2011). 2010 Massachusetts Recreational Boater Survey. Massachusetts Ocean Partnership Technical Report #OC.03.11.	Recreational boating in Massachusetts' coastal and ocean waters contributed $806 million to the Massachusetts economy in 2010. These data are not used in the model because they are not applicable to Narragansett Bay.
Tourism	NOAA Coastal County Snapshots Application (http://www.csc.noaa.gov/digitalcoast/tools/snapshots/)	Provides data on wages, goods and services attributable to tourism and recreation. However, the estimates include coastal activity in the Washington, Newport, and Providence counties. In order to be able to use these data in the model, would need to establish a relationship between nitrogen concentration and tourism and also identify the subset of these data that is applicable specifically to the Bay.
Tourism	Rhode Island Department of Administration, Division of Planning, Office of Strategic Planning and Economic Development. Five-Year Update - Rhode Island Comprehensive Economic Development Strategy. March 11, 2010. http://www.planning.ri.gov/ed2/2010CEDS.pdf	Provides information on the Rhode Island's economic condition and presents the state's overall economic development vision and objectives. Provides useful qualitative information about the role that the Bay plays in the statewide economy, but does not provide Bay-specific tourism data.
Tourism	Ocean Special Area Management Plan, Volume 1, Chapter 6: Recreation and Tourism (http://seagrant.gso.uri.edu/oceansamp/documents.html)	Describes how in the past Narragansett Bay was a popular site for yacht racing activities and regattas. The plan states that coastal tourism in RI is very seasonal, with coastal communities doubling and tripling in population during the summer months. Provides qualitative information about the Bay's tourism but does not provide Bay-specific quantitative data.

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TOPIC	SOURCE	SUMMARY
LID/GI	"Improving Water-Quality in Urban Watersheds Using a High-Efficiency Street Cleaning Program," City of Cambridge, MA	Presentation discusses potential for reducing phosphorus loadings through "high-efficiency" street cleaning in the Charles River watershed. Presents results of using Source Loading and Management Model (WinSLAMM) to simulate phosphorus load reduction from different street cleaner technologies. If we could obtain preliminary results data, we could potentially simulate the effects of non-structural LID/GI interventions like street cleaning on phosphorus loads. Currently 3VS does not model phosphorus.
LID/GI	"An Optimization Approach to Evaluate the Role of Ecosystem Services in Chesapeake Bay Restoration Strategies," EPA ORD, October 2011	Report on implementing a framework for assessing ecosystem service impacts of Green Infrastructure approaches to meeting the nutrient and sediment TMDLs in Chesapeake Bay. Analysis uses highly spatially explicit data sources and modeling tools to determine appropriate implementation of point source controls, agricultural BMPs, and urban stormwater BMPs. Analysis accounts for direct (nutrient and sediment reduction) benefits as well as "bonus ecosystem service" (carbon sequestration, air pollution reduction, flood control) benefits. Illustrates how to model implementation of LID BMPs (both agricultural and urban) in a highly spatially explicit way. Currently, the Narragansett 3VS model does not include the level of spatial precision necessary to reproduce this particular effort.
LID/GI	"BMP Performance Extrapolation Tool for New England," EPA, 2011	This tool can estimate removal efficiency for TP, TSS, and Zinc (but not TN) for biofiltration, dry pond, grass swale, gravel wetland, infiltration basin, infiltration trench, and porous pavement. The important elements for estimating stormwater BMP removal efficiency using this tool to estimate pollutant removal (e.g. P or N when available) or flow volume (IC) reduction for LID BMPs are: type of BMP, design storm volume (expressed as inches over area of IC treated by BMP), and amount of impervious area being treated in the watershed with BMPs. Need to input source area (e.g., comm/res/ind), BMP type, pollutant, and depth of treated runoff (0-2 inches). Could be useful if 3VS is extended to other pollutants.
LID/GI	"Estuary Data Mapper," EPA	Provides spatial data for estuarine watersheds, including land use/land cover, imperviousness (current and projected), and housing density (current and projected). Also has estuarine water quality, precipitation annual and monthly averages, nitrogen deposition, estimated estuarine N and P loads and sources, and projected N and P loads under climate and land-use change scenarios. This could provide a consistent source of useful input data if the 3VS model is applied to other estuaries.

LID/GI	"Blue Cities Guide: Supplemental Materials," the appendices to "Blue Cities Guide: Environmentally Sensitive Urban Development," Charles River Watershed Association, September 2008	Provides extensive descriptions of LID/GI projects, ranging from permeable pavement to green rooftops. Includes cost/effectiveness and implementation examples. Could be used to predict outcomes of using specific LID/GI technologies, though the 3VS model currently focuses on the impacts of regional implementation of LID/GI, rather than specific technologies.
LID/GI	"Forging the Link: Linking the Economic Benefits of Low Impact Development and Community Decisions," UNH Stormwater Center Resource Manual, 2011	Chap 2 reports the removal efficiency of various BMPs for N, P, and TSS as well as O&M costs. Chap 3 looks at case studies and compares conventional to LID costs across several areas to show where investment leads to offsetting savings elsewhere. Maintenance costs are highly variable, so some form of average costs would need to be developed for use in the model. Reported costs are estimates, not actual construction costs, and they mostly apply to new development. Could be a useful source of cost and effectiveness data for a BMP-specific approach.
LID/GI	"Watershed Nutrient Load Reductions & Stormwater Permitting," EPA Surface Water Branch Meeting Presentation, June 2012	Discusses sources of nitrogen and phosphorus in the Upper Charles River Watershed. Includes construction cost curves to reduce impervious area in Milford, Bellingham, and Franklin. Discusses costs and effectiveness for construction. Is highly area specific. Could be used to model costs for reducing nitrogen and phosphorus loading in areas with similar land cover in the future.
LID/GI	"Sustainable Stormwater Funding Evaluation," Horsley Witten Group, September 2011	Explores BMPs available for Milford, Bellingham, and Franklin to achieve desired phosphorus load reductions and costs associated with each option compared to status quo costs. Describes total area, land use, and impervious area of towns within the Charles River Watershed. Also describes BMP unit costs for different types of land cover. If the 3VS model were expanded to address phosphorus loading in the future, this source could be used to model BMP impacts on phosphorus loadings in areas with land cover data.
LID/GI	"Total Maximum Daily Load for Nutrients In the Lower Charles River Basin," MA DEP, June 2007	Provides Phosphorus TMDL for Lower Charles River compared to existing load by sub-watershed as well as by land cover category. Includes seasonal measures of nitrogen, phosphorus, and chlorophyll a. Could potentially be used to show the impacts of loadings in freshwater ecosystems.
LID/GI	"Urban Stormwater Runoff factsheet," DE Dept. of Natural Resources and Environmental Control	Includes cost data and percent reduction in nutrient loading (N and P) for various BMPs. Could potentially be useful for modeling impacts of specific BMPs in the future.
LID/GI	"Rhode Island State Land Use Policies and Plan," Rhode Island Department of Administration, April 2006	Projections of future land use patterns and descriptions of future land use plans; could be useful for defining future land use trends conditions.
LID/GI	"Capturing Rainwater from Rooftops: An Efficient Water Resource Management Strategy that Increases Supply and Reduces Pollution," NRDC, November 2011	Discusses ways of capturing rooftop rain runoff for use in irrigation or, with some treatment, in commercial applications. Quantifies for a sample of cities the amount of rainwater potentially captured from rooftop systems. Could be used to estimate reduction in runoff from implementing rooftop rain capture if that were a form of LID being considered.

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LID/GI	"Research Outcomes on the Efficacy of LID Technologies," UNH Stormwater Center Presentation, March 2011	Presents results of UNH Stormwater research into effectiveness of different LID technologies work. Charts show pollutant removal rate for a variety of pollutants and LID/GI projects. Could be useful for developing a technology-specific approach in future modeling efforts.
LID/GI	"Stormwater Management Strategies for Reduction of N and P Loading to Surface Waters", UNH Stormwater Center, January 2011	Presents data from the UNH Stormwater Center's experiments evaluating the pollutant removal effectiveness of different LID/GI BMPs. Could be useful for developing a technology-specific approach in future modeling efforts.
LID/GI	"Non-Point Source BMP Efficiencies," February 2011	Efficiencies for BMPs by nutrient (N, P, SED) and type (Ag, Resource, Urban). Could be used to model the effectiveness of a wide range of BMPs if a technology-specific approach is pursued in future modeling efforts.
LID/GI	"Historic and Future Phosphorus Loading to the Lower Charles River," EPA Region 1, September 2011	Describes the historic, current, and future trends in phosphorus loadings into the Charles River based on source. Projections are based on planned LID/GI projects which are described in more detail. Could be used to show how implementation of LID/GI reduces phosphorus loadings in future modeling efforts if they address this pollutant. However, would need to further investigate the underlying data to determine whether it could be applied to other watersheds.
LID/GI	"WMOST model documentation," Abt Associates, April 2013	The Watershed Management Optimization Support Tool (WMOST) is a watershed scale model that evaluates the impacts of alternative water resource management options, including LID/GI. It is currently available in a beta version and could provide useful validation of LID impacts. Additional review is necessary to determine if the scale of this model is compatible with the 3VS model.
LID/GI	"GI Benefit in Floodplain Management," Atkins, August 2012	Study measures loss avoidance from the containment of floods using non-specified GI methods. While the study does not describe specific GI projects, the effect of GI on flood control could be extrapolated to other watersheds to determine costs associated with flood damage. In the case of the 3VS model, additional effort would be required to tie flood risk directly to imperviousness, which is the key parameter driven by the use of LID/GI.
LID/GI	"Assessing the Impacts of GI Stormwater BMPS on Stream Communities and Habitats," Naomi Detenbeck, February 2012	Presents results of AED research into impacts of LID/GI BMPs on freshwater ecology at the watershed level. Could be used to show additional environmental benefits of LID/GI, but more work would need to be done to incorporate baseline impairment of freshwater ecosystems and link LID/GI implementation with environmental impacts.

LID/GI	"Fundamentals of Urban Runoff Management: Technical and Institutional Issues," Shaver et al., 2007	Covers many aspects of urban stormwater runoff including impacts to water quality and ecosystems as well as the effectiveness of stormwater management facilities. Chap 3 gives concentrations of various pollutants in urban stormwater, shows variation among several US climatic regions and by land use type. Chap 4 describes relationships between road density and total imperviousness as well as forest cover and total imperviousness, etc. Chap 10 shows removal rates of TSS, P, and N from several different structural facilities based on NJ Stormwater BMP manual. Could be useful in estimating baseline loadings that would be affected by LID/GI.
LID/GI	"Cape Cod Commission Infrastructure Matrix," Cape Cod Commission, October 2012	Describes nutrient management strategies in three main categories: wastewater, fertilizer & impervious surfaces, and water body. Should be particularly useful in developing a 3VS model for Cape Cod.
LID/GI	"The Costs of LID," Stormwater Journal, February 2013	Provides installation cost estimates for BMP on a square foot or gallon basis, as well as annual O&M costs. Describes case studies in different land use types. To the extent that we think costs are similar between Orange County and our study area, these values could be used to model upfront and ongoing costs associated with the described BMPs.
LID/GI	"Triple Bottom Line Assessment of Traditional and GI Options for Controlling CSO Events in Philadelphia's Watersheds," Stratus Consulting, August 2009	For the regions studied, a wide range of benefits are estimated and monetized, including recreational use benefits, residential property value increases, and poverty reduction benefits (from job creation) under different LID scenarios. Benefits are area-specific, and wide ranges are given. We would need additional information about the methodology used in order to apply their results to other areas.
LID/GI	"Scoring Spreadsheet for Recovery Potential Screening in MA", EPA	EPA-developed this screening tool that evaluates water bodies for their potential for restoration. The model connects social and environmental stressors with a wide range of environmental indicators. Could be useful for establishing baseline impairment levels of freshwater ecosystems in order to assess the impacts of LID/GI on such ecosystems.
LID/GI	"Losing Ground: Beyond the Footprint," Mass Audubon, May 2009	Describes development and previous land use patterns in Massachusetts. Includes development rates and levels in MA by municipality. Could be an alternative source of data on projected development trends. For this version of the 3VS model we opted to use ICLUS, which is more easily transferred across different watersheds.
LID/GI	"USDA Natural Resource Conservation Service, Conservation Practices,"	For a wide variety of Conservation BMPs (related to agriculture but some transferable to other land uses) the document describes systems effects qualitatively. Could be used to conceptualize how to apply the 3VS model to characterize LID/GI in rural settings.

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TOPIC	SOURCE	DATA OR INFORMATION DERIVED FROM SOURCE
LID/GI	"Reducing Stormwater Costs through LID Strategies and Practices," EPA Nonpoint Source Control Branch, December 2007	This document presents case studies from various states on LID development, showing costs vs. conventional development. For most sites, several types of costs were considered, including site preparation, stormwater management, paving, and landscaping. Cost savings varied between cases, though LID costs were consistently less than conventional development costs. Extrapolating quantitative estimates from the case studies to the Narragansett Bay watershed would be difficult because costs varied widely depending on the location, even for the same type of project.
LID/GI	"Introductory Webcast on SUSTAIN," EPA, March 2010	Provides an overview of SUSTAIN, a GIS based tool for analyzing stormwater treatment options focusing on GI BMPs. SUSTAIN could potentially be useful as a model input, but it requires a level of data resolution that is more precise than the scale used in the 3VS model.
LID/GI	"Rhode Island Stormwater Design and Installation Standards Manual," Rhode Island Department of Environmental Management/Coast Resources Management Council, December 2010	This document contains technical standards and specifications for the installation of different stormwater management options in RI. It includes guidelines for LID/GI practices in RI but does not contain quantitative estimates of the efficacy of LID/GI practices at a regional scale.
LID/GI	"Planning for Sustainability: A Handbook for Water and Wastewater Utilities," EPA, February 2012	Qualitatively describes plans for sustainably planning and managing wastewater resources and provides examples. Does not contain quantitative data or relationships usable for model development.
LID/GI	"Incorporating GI Approaches into State Stormwater Permits and Programs," EPA Smart Growth Office	Slideshow that focuses on the permitting process, what states can do to encourage GI, and why they should do so. Does not contain quantitative data or relationships usable for model development.
LID/GI	"Storm Water Phase II Annual Program Costs"	RI DEM provided $25,000 to 36 municipalities to develop stormwater management plans. Does not describe the programs or specific BMPs undertaken. Does not contain quantitative data or relationships usable for model development.
LID/GI	"Clean Water Green City", Philadelphia Office of Watersheds	Slideshow making the case qualitatively for Green Infrastructure to deal with stormwater in Philadelphia. Does not contain quantitative data or relationships usable for the 3VS model
LID/GI	"Leveraging Public Spending for Greener Cities", Seattle Department of Planning and Development	Discusses specific areas of Seattle and possible projects. Does not contain quantitative data or relationships usable for model development.
LID/GI	"Green Stormwater Operations and Maintenance Manual", Seattle Public Utilities, August 2009	A pictorial description of various LID/GI projects and how to determine if they're operating optimally. Does not contain quantitative data or relationships usable for model development.

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LID/GI	"Seattle Stormwater O&M Maintenance Package", Seattle Public Utilities	Slideshow describing process for O&M of LID/GI projects. Does not contain quantitative data or relationships usable for model development.